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A SIMULATION MODEL OF THE BIOLOGICAL FUNCTION OF BEEF COWS

by

© MEORI ROSEN

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

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IN

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled A SIMULATION MODEL OF THE BIOLOGICAL FUNCTION OF BEEF COW submitted by MEORI ROSEN in partial fulfilment of the requirements for the degree of DOCTOR OF PHILOSOPHY in ANIMAL PRODUCTION.

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External Examiner

Date Sept. 28/82

ABSTRACT

A deterministic computer simulation model of a cow-calf biological system, programmed in **CSMP/360** was developed and used, for the purpose of characterizing and evaluating the effect of Alberta environmental conditions on the pattern of growth, fertility, and milk and calf production of Hereford (**HE**) Beef Synthetic (**SY**) and Dairy Synthetic (**DY**) range cows.

These variables were modelled to be influenced by genetic group, body condition and plane of nutrition. The simulated nutrient intake was dependent on weight, condition and requirements of the animal, as well as the availability and digestibility of the forage.

The primary consideration in developing the equations representing animal performance was to describe the biological processes as accurately as possible. If all such processes and their interrelationships could be described accurately in quantitative terms, it should also be possible to predict accurately cow productivity.

In the first part of the study, a simulation model was developed and validated. The model (chapter 3) displays daily and periodical changes in weight, milk production, fetal growth, calf growth, feed intake, digestibility, energy utilization, body reserves and grazing activity. Provisions are also made to estimate cow fertility, calf survival and the effect of cold stress. Inputs for the model include genetic potential, forage quality and climatic conditions.

The data simulated by the model approximated changes in weight and calving and weaning traits of the three breeding groups. Differences among breeding groups for the year 1976-77 were simulated and discussed.

In the second part of the study the model was used to investigate the effect of environment on cow weight and reproduction. Three simulation studies were carried out. In the first study (chapter 4), the effect of three management options applied simultaneously was evaluated. The options were improved supplementary winter feeding, controlled temperature of 20°C year round and constant feeding programs of 28% crude fiber under confinement conditions. It was found that there were four periods of change in predicted live weight during the annual cycle of the cow. Energy concentration of the feed was predicted to be the most influential factor during the initial period after calving, and its effect on live weight was mainly via the change in empty body weight. Crude fiber in the feed was predicted to be the most influential factor in the second period during herbage lignification at the end of the grazing season, and its effect on live weight was mainly through the increase in gut fill. Energy deficiency after pasture lignification was predicted to be the most influential factor in the third period and its effect on live weight was predicted to be via decrease in empty body weight. Fetal weight was predicted to make a significant contribution to dam live weight only in the fourth period starting in the last phase of pregnancy.

In the second simulation study (chapter 5), the effect of a severe (colder than average) winter on cow weight and productivity of the three breeding groups was investigated. It was predicted by the model that the effect of severe winter on cow weight would be only temporary and cows from all three breeding groups were predicted to recover in the following grazing season. Fertility, in the season after a severe winter was predicted to be affected to a greater degree than calf weaning weight.

In the third simulation study (chapter 6) the effect of improved milk production was evaluated. This can be achieved by the incorporation of dairy breed-type cows into beef herds. Six variations combining different levels of initial potential daily milk yield (IPDYM) with constant levels of persistency (P), and different levels of P with constant levels of IPDYM, and a combination of the two were compared to a control represented by the Beef Synthetic cows at The University Ranch. The effect of IPDYM on milk production and reproduction was predicted to be more positive than that of P. Increase in IPDYM was predicted to increase weaning weight and to decrease calving interval, whereas improvement in P was predicted to increase both weaning weight and calving interval.

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1. GENERAL INTRODUCTION

In recent years, a primary goal of The University of Alberta Animal Breeding Section, has been to study differences in both biological and economic efficiency of beef production systems involving three lines of beef cattle under different management systems and exposed to different environments.

Previously published analyses (Goonewardene *et al.*, 1981; Willms, 1981; Butson, 1981; Arthur, 1982) using statistical models, provided much information on the genetic potential of three breeding groups (Hereford, Beef Synthetic and Dairy Synthetic), but much less is known about environmental influence on level of production and reproduction of these three groups.

Several workers in this field have recognized the need to compare breeds and breeding management systems in terms of their biological and economic performance. However, the complexity of such comparisons coupled with the time required to carry them out, sharply limit the number of treatments which can be experimentally tested. These limitations have led to increased interest in the use of simulation models, designed to consolidate available information on livestock biology into descriptive mathematical models, which can be used to predict probable responses to specific treatments.

The genetic potential parameters as reported in previous studies, combined with the environmental conditions as recorded during the years, can be used as input for a cow-calf model, which can be simulated to estimate the potential gain of alternate breeding and management systems or, at least to identify the most promising direction for empirical research.

The large amount of research that has been conducted with beef cattle in areas such as nutrition, physiology of reproduction, breeding and physiology of climatic influence has resulted in a large body of knowledge concerning the function of biological subsystems. There have been several attempts in recent years to synthesize this information from the various fields of animal science into a general model, for use in describing production systems (chapter 2). The present study represents another attempt to use the same principles for a comprehensive analysis of daily changes in cow-calf production systems in Alberta.

1.1 GENERAL OBJECTIVES

The main objective of this study was to develop a model of beef cow biological function which would be suitable for the simulation of daily behavior of the system. This could be utilized for system analysis of environmental effects and alternative management systems in Alberta.

Achievement of this goal required:

1. modification of existing mathematical models from the literature to achieve the accuracy, flexibility and

adaptability required for analysis of environmental effects,

2. preparation of comprehensive computer simulation programs, flow charts and input-output formats,
3. validation of the model with experimental data, and
4. analysis of options.

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2. BACKGROUND REVIEW

By building models which represent real systems and by simulating the internal processes of each component of the system, systems research can be used in prediction, decision-making and developing new production alternatives.

Simulation techniques usually encompass two basic activities, namely 1) the building of a theoretical model which closely resembles the actual system concerned, and 2) the subjection of the working model to changes which includes the evaluation of its reactions to these changes.

2.1 SIMULATION

In its most general sense, simulation means the representation of reality. Computer simulation has come into increasing widespread use to study the behavior of systems whose state changes over time. Alternatives to the use of simulation are mathematical analysis, experimentation with either the actual system or a prototype of the actual system, or reliance upon experience and intuition. All, including simulation, have limitations. Mathematical analysis of complex systems is very often impossible; experimentation with actual or pilot systems is costly and time consuming, and relevant variables are not always subject to control. Intuition and experience are often the only alternatives to computer simulation but can be very inadequate.

Problems suitable for simulation analysis are characterized by being mathematically intractable and having resisted solution by analytical methods. The problems usually involve many variables, many parameters and functions which are not well behaved mathematically.

Simulation in animal research involves features of both classical experimentation and formal analysis in a way that provides great flexibility in modelling physiological, biochemical and physical systems.

System simulation has two basic phases, one involving construction of a model and the second concerned with the use of the model in evaluating the system.

2.2 BASIC STEPS OF SYSTEM SIMULATION

Basic steps and linkages of system simulation as suggested by Dent and Anderson (1971) and Dent and Blackie (1979) are illustrated in Figure 2.1.

2.2.1 Definition of the System and Objectives for Modelling

Within the realm of systems research, models may be used to describe and clarify production systems and their interacting components and to provide possible solutions to management problems.

The construction of a descriptive mathematical model places an obligation on those involved not only to identify the sub-systems within their system, but to evaluate the significance of each component and its relation to all others. In this process a thorough search for all existing information and an evaluation of such data are necessitated. Simultaneously, the search exposes gaps in present knowledge and the relative usefulness of existing information. This type of a descriptive application of modelling may lead to a critical analysis of production systems, evaluate past research and guide future investigations.

2.2.2 Analysis of Data

The model design is to a large extent dependent on the data available or on the feasibility of generating data within the time limits set by the research. An ideal structure in the model may have to be forsaken because of data limitations. The structure and the quantification of the model are thus intimately bound together, both eventually influencing the effectiveness of the final model.

2.2.3 Model Construction

The modelling phase consists of developing a mathematical model of a system suitable for operation on a computer. As simulation is usually resorted to because of the unsuitability of analytical techniques, the simulation model will need to include those features of the system which render other techniques unsuitable. These features will usually be related to the complex nature of the system, and the need to follow the behavior of the system through time.

A model suitable for simulation usually contains the following components

1. major subsystems,
2. important components and relationships within each subsystem,
3. links between subsystems,
4. important environmental variables, and
5. control points.

2.2.4 Validation

Having developed the model representing the physical reality and having prepared a computer program on which to run the modelled processes, some test of the model's ability to satisfactorily represent or simulate the real system is required. This evaluation stage is known as model validation, or verification.

In order to validate the model, its forecasting ability should be tested against additional sets of experimental data which have not been used for its construction. The two methods which have been used mostly for testing models are: graphical comparison and the statistical goodness of fit types comparing the estimated and the experimental data. This involves the use of coefficients of variation and coefficients of correlation (Goldman *et al.*, 1978).

2.2.5 Experimentation

Experimentation with simulation models has much in common with physical experimentation, but there are major differences which have implications for the design of experiments and the analysis of results.

The existence and treatment of variation provides one of the main differences between physical and simulated experiments. In physical experiments, there is always an element of variability over which the experimenter has no control. Thus, he must use refined experimental procedures and must attach probability statements to treatment differences in order to infer beyond the experimental data. In simulation experiments, variability is deliberately included in the model and is both controllable and repeatable. The experimenter can thus achieve perfect homogeneity of experimental medium, allowing treatments to be compared under identical conditions.

The objectives of experimentation with simulation models in animal research oriented studies will usually be of the following types:

1. to compare alternative courses of management, and
2. to estimate the response of the system to changes in the level of a single input.

Many of the problems studied via simulation are concerned with the comparison of alternatives. Even if the model is not sufficiently realistic to give a good estimate of the absolute level of system performance, it may still be quite suitable for estimating the relative merits of different alternatives.

When simulation models are used to estimate the response of a system to the level of a single variable input, it is usually the trend in results that is important, rather than the absolute values for any particular level of input. The usual objective with this type of experiment is either to estimate the input level for an optimal level of output, or to examine the response of the system to changes in the level of an input over the whole of its relevant range. This latter objective is often referred to as a sensitivity analysis and the interest lies in the general shape of the response function rather than in its maximum or minimum.

2.3 BEEF PRODUCTION MODELLING

Beef cattle research is primarily concerned with understanding the process within the genetic-environmental system; however, such integrated knowledge has been meaningfully employed by problem-solving modelling approaches which simulate alternative management strategies and result in final values for use in decision-making at both the planning and the implementation stages.

Numerous models have been constructed to study beef production systems. Most of them represented a problem solving type of modelling. In this category two main types of models were used namely 1) optimization models and 2) dynamic simulation models.

2.3.1 Optimization Models

Long *et al*. (1975), Fitzhugh *et al*. (1975) and Cartwright *et al*. (1975) used linear programming models to compare efficiency among cows of different mature weights under different management systems. The linear programming techniques allowed allocation of limited resources in such a way as to maximize net return. Their conclusions reflected the difference between management systems in cost.

Wilton *et al*. (1974), Morris and Wilton (1975, 1976), Morris *et al*. (1976) and Wilton and Morris (1976) conducted a series of studies using linear programming models. They also simulated production of cows of different mature weight and genotype for the purpose of comparing different management schemes.

2.3.2 Dynamic Simulation Models

Boyd and Koger (1974) developed models for the evaluation of beef cattle systems. One model determined nutrient intake and costs for a single cow-calf pair, including postweaning production. The second model used these results to calculate fertility levels, death losses and cow replacement rates. Only simulated "final values" were computed and compared with observed data.

Seligman and Weitz (1978) developed a model for simulating the effect of calving season on the nominal supplementary feed requirement and gross margin of beef grazing on seasonal Mediterranean pasture. This model computed "final values" which may aid in the decision-making process.

Sanders (1977) developed a model for simulating beef cattle production under a wide range of management schemes, with cattle differing widely in genotypes for size, growth and milk production. The model was used to simulate "final values" of feed intake, weight, milk production, fertility and death loss. Sanders (1977) used this model to examine the predicted effectiveness of different selection indices in moving a population of beef cattle towards an optimum combination of traits. Notter (1977) used the same model to investigate factors affecting efficiency of beef production. The factors considered were milk production, mature size and mating systems.

Loewer *et al.* (1980) developed a model, designed to simulate a beef forage strategy which is recommended for use by cow-calf producers in Kentucky. Their model was also concerned only with "final integrated values".

Congleton and Goodwill (1980) developed a beef production model for simulating structures of cow herds and production herds, composed of calves from the cow herd. Their model again was designed to solve problems concerning breeding, management and marketing in terms of "final values".

Only a few studies have dealt with pattern description modelling.

Lavine *et al.* (1981) developed a model for simulating forage intake, energy requirements, liveweight and calving rates of Zebu cows in Llanos, Columbia. This model was built in order to allow continual prediction of the amount of improved pasture or supplemental feed that would be necessary to raise calving rates in a particular herd. The model was fitted to pattern description dynamic modelling by describing output as a pattern of production functions in addition to "final values".

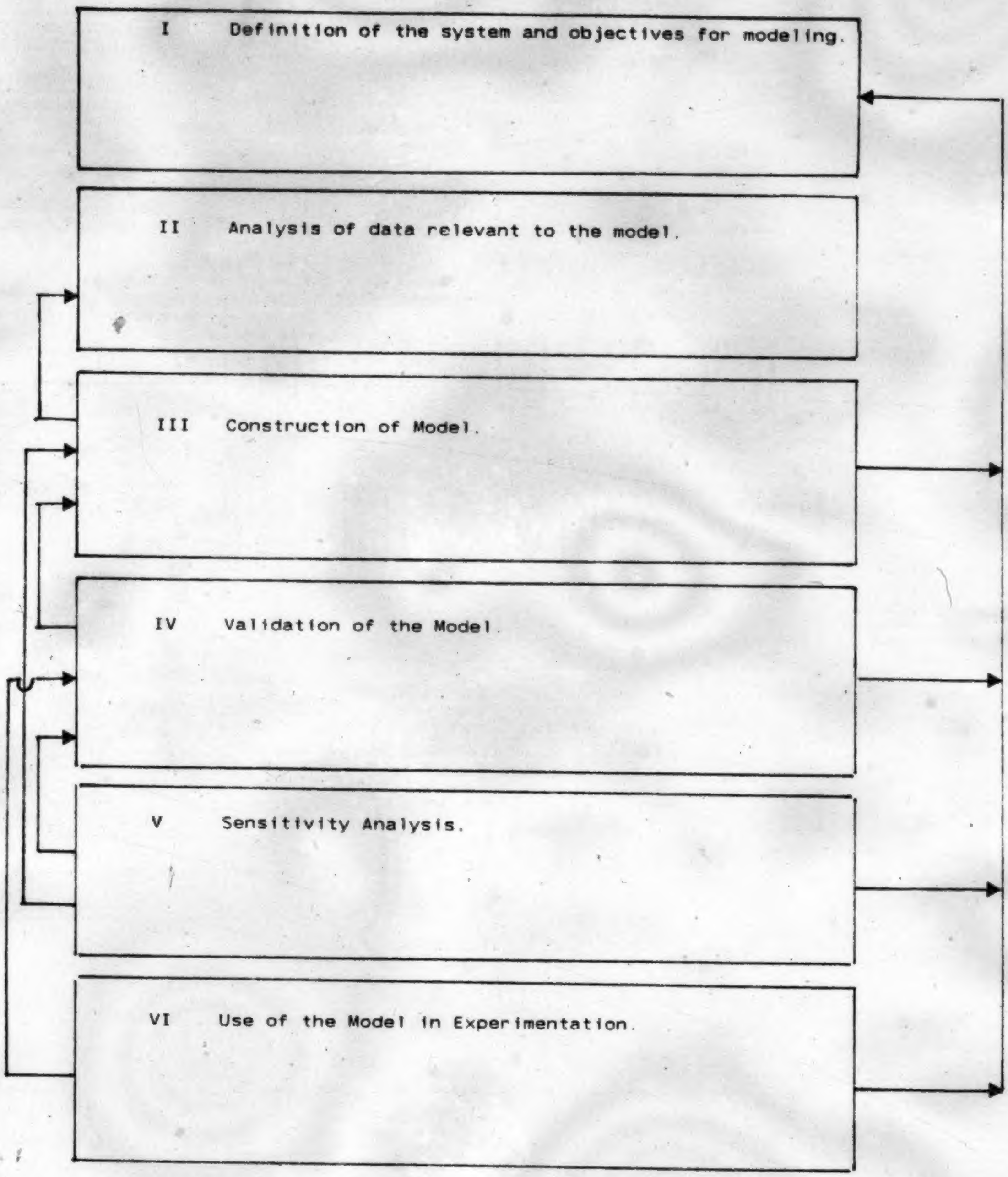
I Definition of the system and objectives for modeling.
II Analysis of data relevant to the model.
III Construction of Model.
IV Validation of the Model.
V Sensitivity Analysis.
VI Use of the Model in Experimentation.

Figure 2.1 The basic steps taken in the course of the study

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3. INTERRELATIONSHIPS AMONG INPUT-OUTPUT FACTORS AFFECTING PRODUCTIVITY OF MATURE COWS OF THREE BIOLOGICAL TYPES IN ALBERTA

3.1 ABSTRACT

A deterministic model for simulating beef cattle production under Alberta management schemes and environment, with cows from three genetic groups: Hereford (**HE**), Beef Synthetic (**SY**) and Dairy Synthetic (**DY**) is described. In the model, the genetic potential (specified as production potential), was reached only if past and present planes of nutrition and climatic conditions were adequate. Intake of pasture or other feeds was simulated as a function of weight, maturity and physiological status of the cows in addition to the availability, digestibility and crude fiber content of the feed.

To simulate cow performance, a dynamic set of blocks was used: milk yield, fetal growth, calf growth, energy balance, grazing management, climatic adaptation, weight and change in body reserve. Cow performance was calculated from the interaction among climatic conditions, nutrient intake, animal condition (reserve depot) and genetic potential.

Evaluation of the model's behavior was made largely by setting climate, grazing and management conditions to those existing at The University of Alberta Ranch at Kinsella, and by validating the simulation output with observed data. This

indicated that the concepts introduced were valid and appropriate to biological and productive attributes of the cow-calf system. It was concluded that within the existing limitations, the model was suitable for testing hypotheses concerned with aspects of environmental conditions, milk yield, calf production and biological efficiency.

3.2 INTRODUCTION

The relationships among dietary quality, environmental conditions, voluntary feed intake (**VFI**) and the productivity of mature range beef cows are multiphasic. The controls on **VFI** and the partition of nutrients among milk secretion, fetal growth and body reserves are still not fully understood. A single or multiple regression equation cannot express the dynamic nature of these relationships. To achieve a complete quantitative description, experimentation with many levels of diverse factors would be required. This complication limits the ability to obtain a clear picture of the interrelationships by experimentation. Systems with even a higher degree of complexity have been treated by simulation modelling successfully (chapter 2).

The simulation model described in this chapter was developed in order to investigate the influence of environmental factors on the genetic-environmental interactive production response in range beef cows in Alberta.

Hence, the objectives of this study were:

1. to develop a model which would best represent the dynamic biological nature of the production of a mature beef cow,
2. to test the model with data from three lines of beef cows under cold winter conditions of Alberta, and
3. to evaluate the behavior of the system by analysis of simulated cow performance for three breeding groups over two well recorded years.

3.3 MATERIALS AND METHODS

The development of an adequate model of any dynamic system for computer simulation requires well defined equations of a few variables as well as accurate estimations of specific parameters. Using widespread sources of literature, the mathematical structure of the model was defined, while input parameters used were estimated from data collected at The University of Alberta Ranch at Kinsella.

3.3.1 Model Development

A multistage procedure was utilized to construct the model (Naylor and Finger, 1967; Mihram, 1972). The steps in its construction were as follows:

1. The cow-calf system was analysed to identify the important elements and determine their interactions.

2. The components and their relationships were structured with flow charts (Figures 3.1, 3.2 and 3.3), and the information needed to support the model was determined and verified.
3. The model as a whole was programmed in **CSMP/360**. Estimates were input without stochastic generators so that the model would be deterministic.
4. The output from the model was compared with historical data to provide a measure of model validation.
5. A limited sensitivity analysis (variable parameter testing) was performed by contrasting the model's responses to variation in the parameters of the greatest interest.

3.3.2 System Description

The model **COW.82** simulates the weight of a beef cow and her calf as a function of environmental parameters namely feed quality and climatic conditions (Figure 3.1). The quality of the feed is defined by its daily crude fiber content (%), and the climatic environment is defined by the average monthly temperature (°C) and the average annual wind speed (km/hr). To simulate cow weight and calf weight, the model calculates daily esimates of feed intake, milk production and fetal growth based on a number of equations and associated values that describe the biological characteristic of an average beef cow.

The equations of the model represent general biological relationships among cow function variables. The effect of cow type or the effect of environmental conditions can influence the performance of the system only if their values are changed from one simulation to the other. The model is designed to provide answers to the following questions: given environmental conditions, how will cows of different biological types perform and alternatively, how will cows of given biological type perform under different environmental conditions.

The model can be divided into six sections (Figure 3.2). One section calculates the potential of the cow based on animal parameters and potential functions for body weight, milk production, reserves and fetal growth. The second section calculates environmental effect based on environmental parameters and environmental functions. The third section translates animal-environment interaction into energy balance in the body. The fourth section calculates gain in reserve tissue, fetal growth and milk yield. In the fifth, cow body weight is calculated as an integral of daily gain in reserve tissue. Fetal weight and body weight adjustments for gut fill are also made. Body weight is used in a feedback mechanism for the calculation of energy balance and gain in reserve. In the sixth section calf daily gain is calculated based on milk availability. Calf weight is integrated from daily gain and used in a feedback to calculate calf milk consumption.

The model is programmed to complete at least two full annual cycles (760) days beginning with a cow just prior to calving. In the first cycle, the parameter values describing the condition of the cow at the begining of the cycle are set entirely on the basis of literature estimates, while in the second cycle many of the parameter values are calculated on the basis of simulated values in the first cycle.

Output values are divided into three groups: 1. primary dynamic output variables which include the body weight of the cow and the body weight of the calf over a period of 760 and 180 days, respectively, 2. secondary dynamic variables which provide additional information on the operation of the biological system on a daily basis (these include: feed intake, digestibility, milk production, energy balance and reserve depot, and 3. a static output variable fertility, which is calculated only once in each cycle. In the model fertility is expressed as open days interval. The model uses the routine FER.82 to translate open days interval into calving distribution units using probability functions for cow herd and bull herd fertility.

The integration interval for solution is set at one day, and rate constants are derived from flux per day. It is possible to vary the integration step size in the CSMP program; however, much of the data from the literature that are used in this model have a resolution of only one day. Sex effect is removed from the model by using the "midsex" (average between male and female) as a calf's sex.

3.3.3 The Mathematical structure

To express the biological function of the cow in mathematical terms, small models (blocks) of biological significance were constructed (Figure 3.3). Two groups of mathematical models were used, one group which included mathematical equations which have been published before, and another group of equations which were constructed for the use in this model from published data. For the second group, data from the literature were analyzed by regression techniques. All equations were verified in small computer programs and their predictive ability was tested by graphically comparing the model predictions with data from the literature. For submodels of low predictive ability, a calibration process was necessary-(calibration is a process where a parameter valve is changed in order to reach reasonable output for a given run (Goldman *et al.*, 1978)).

In the model, equations 3.5 and 3.6 for calf milk capacity, 3.7 for butterfat percent, 3.12 for calf gain from milk, 3.13, 3.14, 3.15, 3.17, 3.18 and 3.19 for feed intake, 3.20.2 for calf gain compostion, 3.27 for cow condition, 3.28 for energy in the milk, 3.30 for fetal ME utilization efficiency, 3.36 for ME concentration in the feed, 3.37 for gut fill, 3.39 for fertility and 3.41 and 3.42 for calf growth were constructed using regression procedures. The rest of the equations were adopted from literature in their original form. The direct relationships among the variables described in this section and the sequence of their appearance is illustrated in Appendix-6.

3.3.3.1 Milk Production

Daily milk yield (**DYM**) is defined as:

$$\mathbf{DYM = PDYM - RDYM} \text{..........(3.1)}$$

where **PDYM** is the current potential daily milk yield (kg/day) and **RDYM** is the reduction in milk yield due to current body condition and energy availability (kg/day). Thus, it is assumed that all dietary components other than energy are nonlimiting, and that there is no health stress that reduces milk production.

The current potential daily milk yield is defined in the model as:

$$\mathbf{PDYM = PDYM1 - DEF} \text{..........(3.2)}$$

where **PDYM1** is the genetically determined potential milk yield in kg, dependent on time of lactation and age of cow and **DEF** is the residual effect of previous milk yield depression due to a deficiency of dietary energy.

Milk yield depression is damped out exponentially (**-AI*DEF**), unless it is depressed anew, due to a subsequent energy deficit (**RDYM**) with an effect larger than the current

DEF (Goldman *et al.*, 1977).

Gains (1927), working with dairy cows, expressed the lactation curve as a function of two parameters: initial daily yield of milk and persistency. This means that theoretically, the genetic potential rate of milk secretion decreases continuously with advancing lactation as:

$$\mathbf{PDYM1} = \mathbf{IPDYM} \cdot e^{-\mathbf{P} \cdot \mathbf{LACTIM}} \quad .....(3.3)$$

where **PDYM1** is the genetically potential daily yield of milk in kg, **IPDYM** is the potential initial daily yield in kg, *e* is the base of the natural logarithms, **P** is the rate of change in the daily yield per month, also termed persistency and **LACTIM** is lactation time (months).

Potential daily milk yield is affected also by age of cow, and can be described by a quadratic equation (Notter, 1977) as:

$$\mathbf{AMCF} = a1 \cdot AGE - a2 \cdot AGE^2 + a3 \quad ....(3.4)$$

where **AMCF** is a correction factor expressed in fractions, **AGE** is age of cow in years and *a1*, *a2* and *a3* are regression coefficients of: 0.1277, 0.0082 and 0.4864, respectively.

The continuously decreasing form of equation 3.3 (Appendix-2-Figure A.2.1) contradicts the traditional shape of lactation curves which are known to have a maximum at 30 to 60 days of lactation (Woods, 1969). In the model the shape of the lactation curve during the first 30 to 60 days is restricted by milk consumption capacity of the calf, so that the final simulated curve fits the traditional pattern (Figure 3.11).

3.3.3.2 Calf Milk Capacity

Plum and Harris (1971) managed Holstein cows as a beef herd, and found that calves were unable to consume all available milk for the first 90 days of lactation. That combined with data from Roy (1970), was used to establish the relationships between calf size and milk capacity.

From the tables given by Roy (1970) two regression analyses were carried out. In the first, the relationship between milk consumption and body weight was evaluated. In the second, the relationship between the ability of the calf to consume energy and body size was evaluated. Energy consumption divided by the caloric value of the milk, was used to give an indicator of the volume of the milk consumed by the calves. The regression equations were then used in a simulation and tested with data presented by Plum and Harris (1971).

It is assumed in the model that there are two main factors which can limit milk consumption by calves: liquid capacity (CIMIC) and energy capacity (the capacity of the calf to consume **ME**)(**CEMIC**) of milk which are computed as:

$$\mathbf{CIMIC} = 0.93 \cdot \mathbf{CWT}^{0.5332} \text{ ....(3.5)}$$

$$\mathbf{CEMIC} = ((0.3678 \cdot \mathbf{CWT}^{0.6727}))/\mathbf{MCLV} \cdot 0.9))\text{...(3.6)}$$

where **CWT** is calf weight in kg and **MCLV** is milk caloric value in Mcals. Maximum milk capacity is the smaller of CIMIC and CEMIC.

3.3.3.3 Energy in the Milk

There is a tendency for the percentage of fat in the milk to increase with advancing lactation (Gains, 1927). Data from Gleddie (1965) indicate, that the rate of increase in butterfat percent in the milk of beef cows can be expressed as a linear function of daily milk yield as:

$$\mathbf{MFTPR} = 5.072 - 0.276 \cdot \mathbf{DYM} \text{ ......(3.7)}$$

where **MFTPR** is percent of fat in milk.

Calf growth from milk alone is a direct function of milk energy yield. Thus in order to simulate calf growth from milk , changes in both yield and fat content should be taken into account. One variable which can express milk yield and energy at once, is the fat corrected milk yield (**FCM**), which is computed (Maynard *et al.*, 1979) as:

$$\mathbf{FCM} = \mathbf{DYM} \cdot (0.4 + \mathbf{MFTPR} \cdot 0.15) \text{..........} (3.8)$$

Relationships of fat percentage to energy value of milk in dairy cows have been reported extensively (Gains, 1927; Tyrrell and Reid, 1965; Maynard *et al.*, 1979). In the model the relationship is expressed (Gains, 1927) as:

$$\mathbf{MCLV} = \mathbf{D1} + \mathbf{D2} \cdot \mathbf{MFTPR} \text{..........} (3.9)$$

where **MCLV** is the caloric value of one kg of milk and **D1** and **D2** are the intercept and the regression coefficient (0.2990 and 0.1122 respectively).

3.3.3.4 Fetal Growth

Live weight and energy requirements of cows during pregnancy are largely affected by the fetal growth pattern. Prior and Laster (1979) determined fetal growth by a serial slaughter study, and presented the fetal growth function as:

$$\mathbf{FTW} = \mathrm{R1} \cdot e^{(\mathrm{R2} \cdot t \, - \, \mathrm{R3} \cdot t^2)} \text{.........} (3.10)$$

where **FWT** is fetal weight in kg, *t* is time from conception in days, and **R1**, **R2** and **R3** are the regression coefficients. The **R2** and **R3** are mathematically responsible for the shape of the fetal growth curve, represented in the model by the constants 0.0738 and 0.0001249. **R1** takes care of the height of the curve, and it is infuenced by breed and age of dam as explained later in this chapter.

3.3.3.5 Calf Growth

Much information exists on the relationships between calf milk energy consumption and growth in dairy calves (Roy, 1970; ARC, 1980; NRC, 1978). Calf growth is strongly related to the metabolizable energy (**ME**) value of the milk consumed by the calf. In the model the **ME** content of the milk is assumed to be 90% of its gross energy (Roy, 1970). Thus, the daily **ME** available to the calf **MME** is:

$$\mathbf{MME} = \mathbf{DYM} \cdot 0.9 \cdot \mathbf{MCLV} \text{..........} (3.11)$$

Data from the NRC (1978) on the **ME** requirements of calves of various live weight and rates of gain were analyzed by multiple regression techniques. The following equation was obtained to determine calf daily gain from milk as:

$$\mathbf{GAIN1} = ((\mathbf{MME} \cdot 0.179) - 0.00033 \cdot (\mathbf{CWTX}^{1.5})) \text{...} (3.12)$$

where **GAIN1** is calf gain on milk alone expressed in kg per day.

Knowing calf birth weight and age in addition to milk energy consumption, enables one to compute calf weight from milk (based on growth from milk alone) (**CWT**) from birth to weaning. To express actual growth in terms of growth from milk, analysis of actual growth (**CWTX**) was conducted and the relationship between the two variables was computed (Appendix-2).

3.3.3.6 Voluntary Feed Intake

Voluntary feed intake on the dry matter basis (**VFI**) is one of the most important environmental input factors affecting the level and efficiency of production in cows (Kleiber, 1961). The relationship between feed quality and **VFI** in the ruminant is not consistent, but rather changes with digestibility. There are positive relationships between the digestibility and the weight of feed eaten for low quality roughage feeds, whereas for high quality feed the relationships are of a negative nature (Conrad *et al.*, 1964; Montgomery and Baumgardt, 1965; Baumgardt, 1970).

In a situation where physical limitation of the gastrointestinal tract capacity sets an upper limit of feed intake, **VFI** is affected only by the rate of passage of digesta and the maximal tract capacity (Campling, 1970; Song and Dinkel, 1978).

Holmes *et al.* (1961) found **VFI** to be affected by age. Song and Dinkel (1978) used this principle and proposed a general mathematical model capable of computing **VFI** considering the composition of feed, available energy and animal maturity.

There are two limits on dry matter intake, a physical limit (**VFID**) assumed to be set by gut capacity, and a physiological limit (**VFIP**) set by metabolic capacity. These can be described as:

$$\mathbf{VFIP} = ((0.1374 - 0.086 \cdot \mathbf{DOM})/\mathbf{DIG}) \cdot \mathbf{EBW}^{0.75} \quad ....(3.13)$$

$$\mathbf{VFID} = (0.0528 - 0.020 \cdot \mathbf{DOM}/(1 - \mathbf{DIG})) \cdot \mathbf{EBW}^{0.75} \quad .....(3.14)$$

where **DOM** is degree of maturity expressed in fractions and **EBW** is empty body weight (kg) and **DIG** is digestibility (fractions).

These equations were constructed based on Song and Dinkel (1978) and data from The University Ranch. Regression equations which were given by Song and Dinkel (1978) were used in a separate **VFI** model. Data was generated based on these equations. The generated data were modified to fit the form of equations 3.13 and 3.14. Data from Price *et al.* (1980) were used to test the behavior of the equations.

In the model, correction factors for feed intake are computed, and **VFI** is adjusted accordingly. Baile (1971) and Bines *et al.* (1969) showed that **VFI** declines as fatness increases. Kennedy (1953) proposed a lipostatic theory of intake regulation indicating that when concentration of some compounds is increased in the blood, **VFI** is decreased. In the model this is described as:

$$\mathbf{LIPOS} = 1-(\mathbf{RES2/EBW})^{0.3} \quad \ldots\ldots\ldots\ldots(3.15)$$

where **LIPOS** is the correction factor for lipostatic effect expressed in fractions, **RES2** is the weight of the reserve tissue (mainly fat) and **EBW** is empty body weight (both in kg). The predictive ability of the equation was tested with data on animals (from The University Ranch) from genetic crosses which were not included in the test of the entire model. The value of the exponent (0.3) was obtained through a process of parameters calibration. The lipostatic mechanism takes effect in the model when the value of the reserves is over 20% of empty body weight.

Taylor (1959) and Campling (1970) found that gut fill and herbage intake were also restricted by abdominal fat. The computation of abdominal fat correction factor is given as:

$$\mathbf{AFTPR} = 0.0072\cdot\mathbf{LWT} \quad \ldots\ldots\ldots\ldots(3.16)$$

$$RVFIF = 1 - (AFTPR/40) \ldots\ldots\ldots\ldots (3.17)$$

where **AFTPR** is abdominal fat (kg), **LWT** is live weight (kg) and **RVFIF** is the correction factor for abdominal fat expressed in fractions. This equation was constructed to approximate data from different sources which were reviewed by Notter (1977). The value of the constant (40) by which **AFTPR** is divided, was obtained through a calibration process. In equation 3.10 abdominal fat was considered to be about 0.72% of cow live weight (Berg and Butterfield, 1976).

Adjustment in **VFI** must also be made for pregnancy and lactation, due to the effect of hormone secretion and abdominal space accupied by the fetus. The correction of **VFI** for fetal abdominal space is described in the model as:

$$RVFIP = 1 - (FWT/400) \ldots\ldots\ldots\ldots (3.18)$$

where **RVFIP** is fetal space correction factor and **FWT** is fetal weight (kg). This equation was constructed to approximate data from different sources which were reviewed by Notter (1977). The value of the constant (400) by which the **FWT** is divided, was obtained through a calibration process.

The correction for lactation is based on a series of calculations given by the ARC (1980) describing the effect of milk secretion on **VFI**.

Voluntary feed intake tends to decrease as ambient temperature increases, and to increase when ambient temperature decreases. Young (1981) indicated that for every 1C° below 20°C (assumed as the optimal temperature for standard intake by the NRC (1976)), the **VFI** is increased by 0.33%.

Biological type has also some effect on **VFI** (Song and Dinkel, 1978). The biological type (**BT**) in the model is described as a combination of two parameters: mature weight (**A**) and initial milk potential (**IPDYM**), and calculated as:

$$BT = (A/480)^{0.75} \cdot (IPDYM/9.3)^{0.3} \text{ ....}(3.19)$$

The values 480 and 9.3 represent mature weight and initial milk potential of Hereford cow. This cow was used as a model in most of the experiment from which the **VFI** equations were obtained. Thus, for Hereford cow the calculated value of **BT** would be one. The exponents (0.75 and 0.3) were obtained through a calibration process.

3.3.3.7 Calf Feed Intake

In the suckling calf, the calculation of **VFI** is complicated by the simultaneous intake of milk and forage. Calf milk intake was described previously. To combine this with pasture intake, it was assumed that daily gain (**GAIN2**) could be used as a good measure of energy retention in the body (Lofgreen and Garrett, 1968).

To estimate the energy retained in the gain (**CNER**) of the calf, the model of Lofgreen and Garrett (1968) was used as:

$$\mathbf{CNER}=(0.05437\cdot\mathbf{GAIN2}+0.00824\cdot\mathbf{GAIN2}^{2})\cdot\mathbf{CWTX}^{0.75}\ldots\ldots\ldots(3.20.1)$$

where **GAIN2** is calf gain and **CWTX** is calf weight. To estimate the proportion of fat and fat-free components in the daily gain of the calf, data from Haecker (1920) was regressed as:

$$\mathbf{CFTGN}=((\mathbf{CNER}/\mathbf{GAIN2})-1.23)/8.6)/0.35\ldots.(3.20.2)$$

where **CFTGN** is the fat in gain expressed as a fraction of the gain (assuming 35% dry matter in the gain (0.35)). **CFFGN** is fat-free in the gain expressed as a fraction of the gain (or 1-**CFTGN**).

Due to differences in the utilization of metabolizable energy for fat and fat-free deposition, the efficiency of utilizing **ME** for growth by the calf (CKf) can be described using information from Notter (1977) as:

$$\mathbf{CKf}=(0.660\cdot\mathbf{CDIG}-0.07)\cdot\mathbf{CFFGN}+(0.333\cdot\mathbf{CDIG}+0.148)\cdot\mathbf{CFTGN}\ldots(3.20.3)$$

where **CDIG** is the digestibility of pasture forage for the calf expressed as a fraction.

The difference between energy requirement for growth (**CMEGR**) and maintenance (**CMEM**), and the energy available from milk (**MMECF**) per unit of pasture energy concentration (**CDEM**) gives calf daily dry matter intake from pasture as:

$$\mathbf{CDDMP} = (\mathbf{CMEGR} + \mathbf{CMEM}\text{-}\mathbf{MMECF})/\mathbf{CDEM}\ldots\ldots\ldots(3.21)$$

3.3.3.8 Digestibility

The percent of digested dry material **DIG** is that consumed multiplied by its digestibility and multiplied again by a reduction coefficient (**RDIG**). **RDIG** (equation 3.22) considers the decline in the marginal increase in digestibility with the increase in percent grain (**GR**) in the ration, as well as the increase in consumption level (**LI**) (Tyrrell and Moe, 1975), and the increase in the difference between ambient temperature and the standard temperature of 20°C (Young, 1981).

The unadjusted digestibility value (equation 3.23) is a linear function of diet quality expressed as a percent of crude fiber in the diet (Song and Dinkel, 1978). The whole set of equations is described as:

$$\mathbf{RDIG}=((105.27+(-4.58+(-0.052\cdot\mathbf{GR})\cdot\mathbf{LI})/100)(1-0.011\cdot(20-\mathbf{TEMP})) \quad ...(3.22)$$

$$\mathbf{DIG1} = (88.0- 1.043\cdot\mathbf{CF})/100 \quad .....(3.23)$$

$$\mathbf{DIG} = \mathbf{DIG1}\cdot\mathbf{RDIG}\quad ....(3.24)$$

3.3.3.9 Energy Balance

The daily energy balance is the difference between available energy and energy demand (**EDM**). The daily available energy is that included in digested feed (**EFD**) plus the energy which may be taken from body reserve (**EBD**). The daily demand for energy is the sum of energy for body maintenance (**BM**), for milk production (**EM**), for fetal development (**EFT**) and for maintaining body temperature under cold stress conditions (**EMH**).

In the model each of these components is calculated first in term of net energy (**NE**), and then converted into metabolizable energy (**ME**) using coefficients for efficiency of utilization of **ME**. These coefficients will now be described.

Maintenance

Maintenance requirements of mature animals are assumed to be proportional to the 0.75 power of weight (Brody, 1945). The **NE** requirement for maintenance are assumed to be 0.077 Mcal **NE**/kg $\mathbf{EBW}^{0.75}$ (Lofgreen and Garrett, 1968). Blaxter (1969) expressed the efficiency of utilization of **ME** for maintenance (**Km**) as a function of the metabolizability of the feed as:

$$Km = 0.546 + 0.3 \cdot Q \text{..........} (3.25)$$

where Q = **ME/GE** (**GE=gross energy**). If **DE** is digestible energy, and assuming **DE/GE** = **DIG** and **ME/DE** = 0.82 (NRC, 1976), equation 3.25 can then be described as:

$$Km = 0.546 + 0.246 \cdot \mathbf{DIG} \text{.......} (3.26)$$

As for body condition, it was shown by Taylor (1970) that **ME** for maintenance declines as body condition increases. In the model this is described as:

$$\mathbf{COND} = 1 - (\mathbf{RES2}/\mathbf{EBW}) \text{........} (3.27)$$

where **RES2** is reserve tissue (kg).

The adjustment of maintenance for lactation was adapted from Moe *et al*. (1972), who found it to increase 7% during lactation. Adjustment of **BM** to metabolic acclimation when the animal is exposed to stressful climate conditions is also necessary (Young, 1981). In the model, this adjustment is based on seasonal changes in thermal environment (monthly average). For each 1C° the cow has previously been exposed to above or below 20°C., 0.8% is subtracted or added to maintenance, respectively. This is equivalent to the value given by Young (1981), but in different units.

Lactation

The relationship between daily milk yield and constituents in milk has been well established in the literature. Schmidt (1971), Gaunt (1973) and Christensen *et al*. (1973) noted that milk butterfat percent (**MFTPR**) decreases with increase in milk yield.

Butterfat is the main contributor to milk energy. Based on butterfat curves described by Gleddie (1965), the relationship between butterfat and daily yield were constructed as described in detail previously in this chapter.

Energy retained in milk is assumed to be equal to the net energy **NE** required to produce 1 kg of milk (**NERM**), and the relationship calculated from NRC (1978) data as:

$$\mathbf{NERM} = 0.3602 \cdot \mathbf{MFTPR}^{0.5236} \quad ....(3.28)$$

Sanders (1977) using data from Moe and Tyrrel (1975) computed the efficiency of **ME** utilization for milk production (**Kl**). He assumed that **Kl** is influenced by change in digestibility. This can be described as:

$$\mathbf{Kl} = 0.81 - (0.1/\mathbf{DIG})......(3.29)$$

Pregnancy

Net energy requirements for fetal growth are derived from Prior and Laster (1979). It is assumed that energy in the fetus is stored mainly in fat and protein. Equations describing change in fat and protein in the fetus with increase in pregnancy were multiplied by the caloric values: 9.4 Mcal/kg for fat, and 5.6 Mcal/kg for protein (Maynard *et al.*, 1979).

Literature estimates of efficiency of fetal growth in cattle range from 0.105 (Moe and Tyrrel, 1972) to 0.25 (Van Es, 1961). Thus, based on the same principles which were introduced in the previous **ME** utilization efficiency items (Km, Kf and Kl), the relationship between utilization efficiency of **ME** for pregnancy (**Kp**) and digestibility was approximated using data from Moe and Tyrrel (1972),. Van Es (1961) and Syker and Field (1972) (sheep) as:

$$Kp = 0.375 \cdot DIG - 0.05 \ldots\ldots (3.30)$$

Growth

It is assumed in this study that mature cows do not have any specific growth requirements. The only change in cow weight is thus considered to be change in reserve tissue.

Van Es (1961) determined the **ME** utilization efficiency of gaining or losing reserve tissue in dairy cows during lactation as: 1.61 Kcal **ME** per Kcal tissue gain and 1.43 Kcal **ME** per Kcal tissue loss. These values can be converted into reciprocal fractional efficiency units **Kf** as: 0.62 and 0.76, respectively.

There is general agreement in a large number of studies with dairy cows, that the deposition of **ME** in reserve body tissue is more efficient in lactating cows than that which occurs in normal fattening nonlactating cows.

In the model the **ME** utilization efficiency for weight change **Kf** in dry cows is the common one which was given by Blaxter *et al.* (1969) as:

$$Kf = 0.03 + 0.81 \cdot Q \ldots\ldots (3.31)$$

when metabolizability (Q) is expressed in digestibility units:

$$Kf = 0.03 + 0.662 \cdot DIG \ldots (3.32)$$

It is assumed in the model that during lactation **Kf** is constant with a value of 0.62 (Van Es, 1961). In the model the constant value of **Kf** for tissue loss was reduced by 0.06 units (0.70) based on similar values presented by Goldman *et al.* (1978).

Climatic Stress

When cattle are exposed to thermal environments below their lower critical temperature, an additional energy component (**EMH**) is added to the daily energy demand. The lower critical temperature (**Tc**) is defined as the effective ambient temperature below which an animal must increase the rate of heat production to maintain the same level of productivity and to prevent a fall in body temperature. The **Tc** is calculated based on Young (1981) as:

$$Tc = 39.0 + (0.36 \cdot IE) - H \cdot (IE + ITT) \ldots\ldots (3.33)$$

where 39.0 is body temperature in °C, 0.36 is assumed the minimal loss of heat by evaporation (Blaxter and Wainman, 1961) in $Mcal/m^2.d$, **H** is the heat production from normal digestion and metabolism at environmental temperature slightly above **Tc** in $Mcal/\ m^2.d.$, calculated as:

$$H = (EFD - (MRE + FRE))/SA \ldots (3.34)$$

where **EFD** is energy in the feed in Mcal of **ME**, **MRE** and **FRE** are the **NE** content of milk and fetus in

Mcals and **SA** is the surface area of the cow (assumed $(0.09 \cdot (\mathbf{WCOW\text{-}liveweight})^{0.67})$) in m^2, **ITT** is coefficient of tissue insulation ranging between 2.5 °C.m²$\cdot$d/Mcal in a new born calf and 12.0 °C.m².d/Mcal in an adult animal and **IE** is coefficient of external insulation ranging between 3.0 to 17 °C.m².d./Mcal depending on the coat depth and the wind speed (Young, 1981).

The increase in energy demand in environments colder than the animal's **Tc** is given as:

$$\mathbf{EMH} = \mathbf{SA} \cdot (\mathbf{Tc} - \mathbf{TEMP})/(\mathbf{ITT} + \mathbf{IE}) \ldots\ldots (3.35)$$

where **TEMP** is the ambient temperature.

3.3.3.10 Energy in the Feed

Energy in the feed is the feed consumed multiplied by its energetic content. The relationships between crude fiber content (**CF**) and **ME** concentration in feed (**DME**), have been well established in the literature (NRC, 1976). Using the NRC (1976) as a source of data, the relationship between **ME** concentration and crude fiber content of the feed was calculated by regression techniques. Substituting equation 3.23 for crude fiber, the relationship between **ME** concentration (**DME**) and digestibility were constructed as:

$$DME = 4.112 \cdot DIG - 0.115 \ldots\ldots (3.36)$$

Data predicted by the equation was found to fit similar data presented by Song and Dinkel (1978).

3.3.3.11 Body Reserve

Body reserve (**RES**) is defined as a storage of energy, into which daily surpluses over demand are put, or out of which energy is taken to cover deficit in supply. Goldman *et al.* (1976) determined reserve tissue in high producing dairy cows at parturition as being 9 to 10 percent of empty body weight. Taking into consideration the difference in condition between dairy and beef cows at calving, it was assumed that reserve tissue in beef cows at calving time is only 4 to 5 percent of empty body weight. Thus, the initial value of the reserve (**RESI**) is a multiplication of 0.196 body weight expressed in Mcal.

Cows can gain or lose reserve energy. The reserve rate of change (**RESCH**) of a cow gaining in reserve energy (**EGAIN**), differs from that of a cow depleting reserve energy (**ELOSS**) according to the balance of energy and weight exchanges in different stages of the physiological cycle (ARC, 1980).

The caloric value of reserve tissue (**CVGN**) is not uniform, but changes with change in physiological status and condition of the cow, It was estimated in different studies as ranging from 3.41 to 7.6 Mcal/kg (Notter, 1977). In the model caloric value of gain is 4.91 Mcal/kg, assuming 70% fat in reserve tissue dry matter (Reid and Robb, 1971). Berg and Butterfield (1976) described a study which was carried out by Reid. Who, working with sheep found that realimentation following weight loss resulted in lower levels of fat and higher levels of water and protein than were maintained during positive growth or on a weight losing regime. Thus, caloric value of the gain is set at 3.50 Mcal/kg gain in periods of copensatory growth.

The potential to use reserve energy (**PDRU**) is restricted to 5% of the reserve per day. The weight of the reserve storage (**RES2**) is calculated in the model by an integration of gain or loss in **RES** devided by its current caloric value.

3.3.3.12 Body Weight

There are three body weights calculated and used in the model;

1. a hypothetical potential live weight, computed first as initial weight (**WCOWI**) and as a reference live weight (**LWT**) thereafter (Appendix-1).
2. an actual live weight (**WCOW**), and
3. an empty body weight **EBW** which reduces live weight by gut fill and fetal weight.

To estimate changes in empty body weight, gut fill should first be known. Gut fill can vary widely according to animal weight, physiological state, and physical and chemical characteristics of the diet. Using data from (Haecker, 1920; Moulton *et al.*, 1922; Price *et al.*, 1980) a multiple regression analysis was carried out, and **EBW** expressed as a percentage of **LWT** was computed as:

$$G = 0.87 + (12.3 - (1.38 \cdot \mathbf{CF}))/\mathbf{LWT}) \ldots . (3.37)$$

Very similar equations were reported by Song and Dinkel (1978) and the ARC (1980).

Empty body weight is calculated first as an initial empty body weight (**EBW1** = **LWT**·G), so that the live weight (**WCOW**) can be computed thereafter on the empty body basis as:

$$\mathbf{WCOW} = (\mathbf{EBW1}/G) + \mathbf{RES2} + \mathbf{FWT} \ldots . (3.38)$$

The current empty body weight is the initial **EBW** plus **RES2**.

3.3.3.13 Timing

There are four time scales used in the model:

1. a real time scale (**TIME**) which is the actual calender in days from day 0 to day 760,
2. a lactation calender (**LACTID**) starting at calving and

ending at weaning each year,

3. a gestation calendar (**GSTIM**) starting at conception and ending at calving (**CVDATE**) each year, and
4. a grazing calendar (**HRA**) starting in the beginning of April and ending in December each year.

In addition to the real time calendars there is a monthly calendar which computes the current month based on sum of days in each month.

In the model, the first calving occurs at time zero, while the first conception occurs 75 days later. Gestation length (**GL**) and age of calf at weaning (**WENTIM**) are defined in the input parameters. New calving occurs **GL** days after last conception, and subsequent conception occurs only if all the following four conditions are fulfilled:

1. At least 330 days have passed since last conception.
2. The cow is in a non negative energy balance.
3. The season is a breeding season and there are bulls present in the herd.
4. The reserve tissue ranges between 12 and 20 percent of the empty body weight.

These four assumptions are based on a large body of literature. For the first set of conditions it was shown by Wiltbank and Cook (1958) that the average interval from calving to first corpus luteum was 53 days in nursed cows. If **GL** is computed as being 283 days on the average, the minimal time taken from one conception to the next sexual cycle is on the average 336 days.

Wiltbank and Cook (1958) also reported a 43% difference in conception rate between cows gaining and losing weight during the breeding season. In addition 14% of the cows losing weight did not show heat at all. Schilling and England (1968) showed that weight change during the breeding season had a highly significant effect on calving percentage. They calculated an increase of 0.203% in calving rate with each kg gained during the breeding season. Based on this, it was assumed in the model that, as long as cows were in a negative energy balance (weight loss), conception is postponed.

Cow condition appears to be the major criterion influencing fertility in the cow. Wiltbank (1981) reported that within 60 days after calving only 46% of the cows which were thin at calving were cycling compared to 61% of the cows in moderate condition and 91% of cows in good condition. This suggested that a minimum level of stored, easily mobilizable energy is necessary for ovulation and cycling in cows. It was suggested also that storage and metabolism of estrogen is connected directly to adipose tissue (Brown and Strong, 1965). Frisch *et al.* (1977) indicated that if there were a method to count the number of cells of adipose tissue due to the interaction between adipose tissue and gonadal hormones, cycling might be determined by change in adipose tissue. In the model, reserve depot tissue was selected to represent adipose tissue, so that cycling could occur only if a certain level of this tissue is obtained. On the other hand, it was shown by Arnett *et al*. (1971) that obesity is detrimental to fertility, so that an upper limit should be set as well. An interval ranging between 12 to 20 percent was selected after the model was simulated, and compared with different sets of data from The University Ranch.

3.3.3.14 Grazing

In a cow-calf system, the pasture is the most important nutritional resource. To increase the model's flexibility, a grazing subprogram was incorporated. Since herbage dynamics was not a primary objective in this study, the usual concept of grazing dynamics has not been implemented here, and pasture growth is not a function of soil and climate, but a function of time. The form of the herbage growth equation is based on work by Bailey *et al*. (1980), and it is given as a monomolecular growth function. Herbage is not divided into green and dry as traditionally has been done, but crude fiber concentration of herbage is given as a function of grazing time (**HRA**). The content of crude fiber in the pasture is given in the model as a curvilinear function of time. In the model the value of the crude fiber in the pasture is changed from 20% in April to 25% in August and to the upper level of 40% in September (Smoliak and Bezeau, 1967). Pasture quality remains constant from September to the next grazing year (starting in April).

Herbage growth is calculated daily. The quantity eaten by the grazing animals is deducted, and a new herbage weight is computed based on the monomolecular growth function. Changes in herbage dry matter digestibility are made in accordance with daily changes in crude fiber due to plant aging. It is assumed that no dry matter is lost by weathering processes.

Computation of forage intake is based on

1. availability of forage expressed as kg/acre,
2. the potential **VFI** of the animals consuming the forage, and
3. the stocking rate (**ANIDP**) which is set in the model as a parameter.

Availability factors are used to modify maximum intake as determined by the animal when forage is limited by heavy grazing. The 0.0007 coefficient used in the model for availability was used previously for sheep by Vickery and Hedges (1972). The model provides three management controls over grazing: stocking rate, first day of pasture (**DELAY1**), and supplemental feeding (**SU**) which is set up to provide the animals with grain and hay.

It was decided to expose the pasture to the highest possible grazing pressure before availability becomes a limiting factor. Stocking rate was thus increased by increments of 0.1 cows/acre starting at 0.2 cows/acre. Biomass removal was then simulated and it was found that 0.8 cows (and their calves) per acre year round was the highest density which did not influence voluntary consumption. Thus ,stocking rate in the model was set at 0.8 cows/acre.

3.3.3.15 Fertility

A quantitative model to predict the percentage of cows that will conceive during a specific time period was described by Sanders (1974). In his model factors such as genotype, age, weight, rate of change in weight, time since calving and lactation status were used as a basis for the equations. A different approach is taken in this model for the computation of conception rate and distribution. There are two basic functions: cycling distribution of cows (**FFERT**) (Wiltbank and Cook, 1958) and probable sexual activity of bulls (**FBULL**) (Figure 3.4).

It is assumed that the distribution of cow cyclings are connected to the average open days simulated by the model. Thus, a fertility coefficient **FERT1** is computed as:

$$\mathbf{FERT1} = (0.8/\mathbf{FFERT1})\ldots\ldots(3.39)$$

where **FFERT1** is the accumulated fraction of cows which are expected to be in heat after "open days interval" period of time. The adjusted cycling (**FERT**) is computed as:

$$\mathbf{FERT} = \mathbf{FFERT}\cdot\mathbf{FERT1}\ldots\ldots(3.40)$$

where the maximum value of **FERT** is 0.950.

A multiplication of **FBULL** with **FERT** yields the final conception distribution and rate which is directly converted into calving distribution and rate.

3.3.3.16 Calf Death Loss

Calf survival has been described in different studies as a function of the environment, dam condition, calf age and growth rate (Notter 1977). Using data from The University Ranch no such relationship has been found. Thus, it was decided to use an average calf death loss of 1.3% per month which is the average rate at The University Ranch. Weaning rate then, will be a multiplication of calving rate by the number of months to weaning and by 1.3%.

3.3.4 General Assumptions

1. The cows are on a seasonal pasture year round. During the grazing season (Spring, Summer) total feed requirements are obtained from pasture, whereas during the winter (December to April) consumption is made up of hay, straw and grain.
2. Weaning takes place 180 days after calving.
3. Supplementary feed energy is computed according to the NRC (1976).

The management system at The University Ranch as a whole was described in detail by Berg (1978).

3.3.5 Estimated Parameters and Procedures

3.3.5.1 Growth Parameters

Cow birth weight **BWT** and preweaning growth **GN** is required for the computation of her life-time potential growth. **BWT** and **GN** for **HE**, **SY** and **DY** were set at: 32.8 and 0.776, 34.6 and 0.932 and 38.2 and 1.011 kg, respectively. Degree of maturity at birth in **HE** and **SY** was set at 6.8%, whereas for **DY** it was 7.4%. (Appendix-1).

3.3.5.2 Gestation Length and Calf Birth Weight

As explained in the section on fetal growth, equation 3.10 is used in the model to calculate calf birth weight. For mature cows, R1 is a constant and its values for **HE**, **SY** and **DY** were set at: 0.0006391, 0.0006970 and 0.0007822, respectively. These parameters were obtained by a covariance analysis of data from cows used for artificial insemination, where the gestation length was used as a covariate and birth weight of the calf as the dependent variable. Age of dam , year and sex were also included in the model. Gestation length in the same analysis was found to be 286.2±0.3, 283.4± 0.4 and 282.2±1.4 days for **HE**, **SY** and **DY**, respectively.

3.3.5.3 Calf Growth

As described in Appendix-2, regression equations were formulated to describe the relationship between **CWT** and **CWTX** as:

$$\mathbf{CWTX} = (\mathbf{GRP0} + (\mathbf{GRP1} \cdot \mathbf{LACTID}^{\mathbf{GRP2}})) \cdot \mathbf{CWT} \quad \text{....(3.41)}$$

where **GRP1** and **GRP2** are the regression coefficients and **LACTID** is current time of lactation (days). **GRP0** is computed as:

$$\mathbf{GRP0} = 1 - \mathbf{GRP1} \cdot \mathbf{LACTIN}^{\mathbf{GRP2}} \quad \text{....(3.42)}$$

where **LACTIN** is the time at which the change in total gain first passes the change in milk rate of gain (simulated gain on milk alone). The values of the regression coefficients **GRP1** and **GRP2** were derived as 6.4527E-5 and 1.8 for **HE**, 4.746E-5 and 1.5 for **SY** and 5.0E-4 and 1.5 for **DY**.

3.3.5.4 Milk Fat

The general equation for butterfat as described in the milk production section is too general to fit different breeds. Thus, based on data from Gleddie (1965) and Butson (1981) which were analyzed by least squares techniques, breed muliplicative correction factors of milk fat were calculated to fit equation 3.7 and found to be : 1.3, 1.25 and 1.26 for **HE**, **SY** and **DY**, respectively.

3.3.5.5 Body Reserve

It was assumed that the initial value of reserve tissue in the body is 5% of empty body weight, and that the maximal amount of reserve which can be converted into mobilized energy is only 5% from the entire reserve tissue in the body per day (Goldman *et al.*, 1978).

3.3.6 Validation Procedures

The performance of the model was tested in three ways:

1. A graphical presentation comparing the values of the model with the experimental results.
2. The coefficient of variation (CV) of forecast deviations, relating them to the average observed values in percent.
3. The correlation forecast (r^2); i.e. correlation between model-simulated and experimental-observed data.

3.3.7 Data

Data obtained from The University of Alberta Research Ranch at Kinsella were handled in three separate sets. One set which included the entire population of the three breeding groups: **HE**, **SY** and **DY** was used for general parameter esimation. The second set which included observations on the same three breeding groups, was from animals participating in the milking experiment (Butson, 1981) and was used for the validation of cow weight. The third set of data included cows from all three breeding groups in which the cows genetic group was the same as their calf genetic group (as defined by their breed code in the ranch record). This set was used for the validation of the model results as a whole except for cow weight.

3.4 RESULTS AND DISCUSSION

NOTE: The results discussed in this section are those predicted by the model. The detailed timing index for the graphs is illustrated in Appendix-5.1.

3.4.1 Calving and Weaning

Simulated and experimental weaning results of the three breeding groups: **HE**, **SY** and **DY** are presented in Table 3.1. Experimental weaning weights in both years (1976-77) were fairly similar and so were the simulated results. For **SY** and **DY** the simulated weaning weights were a bit lower than the actual.

Calving distribution is presented only for 1977, since the "open days interval" for 1976 in the model was set by the initial conditions. The validation of simulated calving distribution revealed that despite the large deviation in some particular cases, the general picture responded appropriately. Sanders (1974) presented a model of reproductive performance in cattle, using a completely different approach. In his study the validation process showed the same degree of accuracy in predicting calving

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Table 3:1 A comparison between simulated and experimental calving and weaning results of cows from three breeding groups over two years.

Breeding Group		Calving					Weaning				
		Distribution %			Rate %	Interval days	Weight Kg		A.D.G Kg/day		Rate %
		30*	60*	90*			76**	77**	76**	77**	77**
HE	Simulated	51.2	81.8	85.1	85.1	367	171.5	171.4	0.756	0.761	79.0
	Observed	45.2	77.5	83.0	83.0	369±0.9	170.1±3.3	169.3±2.8	0.776±0.018	0.776±0.015	80.0
SY	Simulated	54.6	86.3	89.7	89.7	358	211.1	210.0	0.966	0.961	83.4
	Observed	53.0	79.0	82.0	82.0	368±0.8	204.0±2.2	204.2±1.8	0.940±0.012	0.950±0.069	79.0
DY	Simulated	50.0	78.9	82.1	82.1	370	228.0	227.3	1.036	1.033	76.3
	Observed	49.3	77.7	82.2	82.2	370±1.6	225.2±3.8	222.8	1.015±0.060	1.017±0.072	76.0

*-Days from the begining of the calving season.

**-The year 1976-(76) and 1977-(77).

distribution as in this study. In a least squares analysis on the observed calving intervals of the same population of cattle, it was found that there were no significant differences between breeding groups (Appendix-3). As for the simulated calving interval, no differences were found between **HE** and **DY** cows when compared to the experimental results, but for the **SY** cows the simulated calving interval was shorter by 10 days than the actual interval.

The same results but in the opposite direction were found for calving rate- a high correlation between simulated and observed results for **HE** and **DY** cows, and some differences for **SY** cows. Evidently this deviation can be attributed to change in estimated reserve tissue in **SY** cows which would tend to influence estimated conception time, and could be different from the general approach which was presented in the model.

3.4.2 Cow Weight

A graphical comparison of the simulated and the observed live weight of all three groups is shown in Figures 3.5 through 3.7. The coefficient of correlation (r^2) and the coefficient of variation (CV) between simulated and observed live weight are given in Table 3.2.

Some of the difference between the simulated and observed patterns of weight can be attributed to the fact that the observed data included more missing data points

Table 3.2 The coefficient of variation (CV) and of correlation (r^2) for live weight of mature cows

Breeding Group	Number of Cows	CV (%)	r^2
HE	103	2.87	0.921
SY	225	2.13	0.950
DY	61	3.39	0.889

than the simulated, so that the observed curves fluctuated much less than would be the case if they were recorded more frequently. The difference among groups in simulated weight is presented in Figure 3.8.

3.4.3 Dry Matter Intake

Due to lack of experimental information on the amount of dry matter consumed by beef cows from pasture, the simulated dry matter intake of range beef cows was compared with data calculated from NRC (1976). Good agreement was found.

The simulated total dry matter intake for both years (1976-77) and the distribution of dry matter between pasture and supplementation is presented in Table 3.3. The supplementary feed was forced into the model in the beginning of December and removed in the beginning of April. The simulated amount of supplementary feed which was consumed by the cows fitted that which was reported by Berg (1975).

Beef Synthetic and **DY** were estimated to consume 5% more supplementary feed and 8% more from pasture than the **HE**. Of the total amount of simulated dry matter removed from pasture, 83.6, 78.9 and 76.6 percent was consumed by the cow and 16.4, 21.2 and 23.4 percent by the calf in **HE**, **SY** and **DY**, respectively. About 28% of the total consumed dry matter was simulated to come from the supplementary feed.

Table 3.3 Simulated dry matter intake for cow and calf from three breeding groups over two years.

Item	Breeding Group	1976 Kg	1976 %	1976 Kg/day	1977 Kg	1977 %	1977 Kg/day
COW							
Total							
	HE	2445.3	100	6.7	2493.9	100.0	6.8
	SY	2677.3	100	7.3	2675.2	100.0	7.4
	DY	2621.8	100	7.3	2698.1	100.0	7.4
Pasture							
	HE	1763.1	72.1	7.0	1808.2	73.0	7.1
	SY	1913.7	72.0	7.5	1956.2	72.0	7.6
	DY	1911.4	73.0	7.5	1984.6	73.5	7.8
Supplementation							
	HE	682.2	27.9	6.2	685.7	27.0	6.2
	SY	715.1	28.0	6.5	718.3	28.0	6.5
	DY	710.4	27.0	6.4	713.5	26.5	6.5
CALF							
Milk (180 day basis)							
	HE	128.2	27.1	0.71	128.6	26.9	0.71
	SY	153.0	23.0	0.85	151.1	23.3	0.84
	DY	170.2	22.5	0.95	168.2	22.3	0.93
Pasture (100 day basis)							
	HE	345.0	72.9	3.4	348.7	73.1	3.5
	SY	511.3	77.0	5.1	498.1	76.7	5.0
	DY	586.2	77.5	5.9	584.0	77.7	5.8

Calves were simulated to consume only pasture and milk (no creep was provided). Hereford calves consumed milk and pasture in a different ratio than that consumed by the **SY** and **DY** calves. While **HE** calves consumed 27.1% of their total simulated dry matter from milk, **SY** and **DY** consumed only about 23%. The remaining 72.9 and 77.0% were estimated to come from pasture. As described in detail in the section on milk consumption, the total estimated consumption of **HE** calves was less than that for the two other groups. Since the **HE** calves were limited by their dry matter consumption capacity, the portion of milk in their entire daily intake was estimated to be somewhat greater than that of the two other groups.

The model predicted that dry matter intake would increase by 2.0 and 2.9 percent for **DY** and **HE** cows respectively from 1976 to 1977. No increase was predicted for **SY** cows and that was attributed to the slight lipostatic depression which was predicted to occur during the second cycle.

The pattern of the simulated dry matter intake of the cows from the three breeding groups is shown in Figure 3.9. The general shape of the dry matter intake curve was very similar to that presented by Forbes (1977) for lactating and pregnant grazing ewes.

Immediately after calving, intake was predicted to rise steadily due to lactation. Then in the fourth month of lactation intake reached an upper physical limit, mainly in the high producing cows (**DY** and **SY**), which predominated for the rest of the lactation period. In the **SY** cows, a simulated intensive fattening process soon after the peak in dry matter consumption caused the lipostatic effect to intervene and feed intake was slightly reduced in the second cycle as shown at time 480 days in Figure 3.9.

After weaning, due to the decline in the cows' requirement and the decrease in pasture quality, daily dry matter consumption of cows was estimated to drop drastically.

In December (240 days after parturition), a feed supplement of better quality from that of November pasture was provided. This combined with a drop in temperatures, caused a slight increase in the cows' predicted feed intake.

From the 7th month of pregnancy (about 300 days after parturition), physical limitation on intake, (which was invoked by the growth of the fetus) and relatively moderate quality supplementary feed caused a slight decrease in predicted feed intake.

3.4.4 Digestibility

Lack of information concerning the digestibility of pasture at The University Ranch at Kinsella, forestalled the validation of simulated digestibility. Simulated digestibility on a daily basis is presented in Figure 3.10.

The University Ranch is at the edge of the boreal forest, and is characterized by groves of aspen poplar and other brush as described by Moss (1955). Smoliak and Bezeau (1967) collected and analyzed different native grasses and shrubs at five stages of growth, and found digestibility (calculated on a crude fiber basis) to range from about 67% to 46% from stage one to five, respectively.

The seasonal pattern of simulated digestibility was quite homogenic in all groups, except for the period where the lipostatic depression in the SY cows reduced feed intake which resulted in a slight increase in digestibility. Pasture digestibility was estimated to be from about 63% in May-June to 45% in October-December.

Immediately after calving there was an increase in digestibility which reached a peak in mid June, following the increase in crude fiber content. In September, due to the sharp increase in crude fiber, the digestibility dropped dramatically, and remained low (about 45%) till December when more digestible supplementary feed was provided (about 55%).

Notter (1977) used digestibility as an input parameter for his model and found it to range from about 48% in the winter to about 67% in May-June. His cow herd was assumed to be pastured on green forage alone from May to October, and on dried forage (hay) from November to April. Thus, the digestibility given for the latter period was for supplementary feeding.

3.4.5 Milk Yield

Simulated milk consumption of the calf in the three groups is shown in Figure 3.11. Three phases were observed in the simulated calf milk consumption pattern. The first, was characterized by a period of increase in consumption and was limited by calf milk capacity. The second which came immediately after the peak point, was characterized by a period of decline in consumption and was limited by cow milk yield potential. The third (which came towards the end of the lactation period before weaning), was brought about by limited energy availability for the cow. The peak point in all three groups was simulated to occur at almost the same time during the month of May: 39, 40 and 44 days after calving in **HE**, **SY** and **DY**, respectively. Since **DY** cows had a greater milking potential, their production estimates were higher than the **SY** cows, and **SY** higher than the **HE** cows.

Total milk and fat corrected milk consumption and the reduction in milk (**RDYM**) due to cow energy deficit included "past effect" (**DEF**), by group and by year are presented in Table 3.4. The estimated yield in 1977 was slightly lower than that in 1976 due to a reduction in milk production and "past effect", derived from a colder fall. In all groups, milk reduction was predicted to increase from 1976 to 1977, so that cow yield decreased. The difference between potential and simulated milk consumption is refered to here as total milk loss. In **HE** cows, total milk loss was predicted to increase by 17.9% from 1976 to 1977. For **SY** and

Table 3.4 Simulated milk production of cows from three breeding groups over two years.

Breeding Group	Year	DYM	FCM	RDYM Kg	DEF	Total
HE	1976	986.8	1065.0	7.1	17.4	24.5
	1977	989.5	1064.8	8.1	20.8	28.9
SY	1976	1177.1	1180.3	4.7	14.7	19.4
	1977	1162.0	1164.5	6.6	34.5	41.1
DY	1976	1309.0	1273.0	5.8	16.4	22.2
	1977	1290.1	1257.0	19.5	42.0	61.5

DYM -daily milk yield
FCM -corrected milk yield
RDYM -milk reduction due to energy deficiency
DEF -loss of milk due to past effect
Total-RDYM+DEF

DY the predicted figure was higher, at 111.8% and 177.0%, respectively. This increase in total loss of milk was derived from the increase in the relative loss caused by the past effect (**DEF**). It is evident that the larger the milk potential of the breed, the larger will be the loss of milk in year of suboptimal conditions compared to a year of optimal conditions.

3.4.6 Energy in the Milk

The simulated milk butterfat percentage (butterfat percentage) of the three groups is shown in Figure 3.12. The increase in daily butterfat percentage from May to October was predicted to be: 0.23, 0.24 and 0.25 percent in **HE**, **SY** and **DY** cows, respectively. This can be attributed to the nature of the function with which butterfat percentage was simulated, characterized by a negative relationship between daily milk yield and butterfat percentage. Since the relative change in daily milk yield from peak point to weaning point in the **DY** group was the largest (due to larger drop in daily milk yield during the terminal lactation phase), the change in butterfat percentage was the largest too. These results for **DY** and **SY** approximate the data obtained from Butson (1981), where daily changes in butterfat percentage from June to September were: 0.0244, 0.1848 and 0.1918 percent for the **HE**, **SY** and **DY** respectively.

3.4.7 Fetal Growth

The simulated fetal growth from conception to birth is shown in Figure 3.13. Since the parameters describing the shape of the curve were taken from Prior and Laster (1978), fetal development for all three groups shows the same pattern. But, due to differences in birth weight and length of gestation among the groups, the height of the curves appeared to differ.

3.4.8 Calf growth

The simulated calf growth on dam's milk alone, and the actual growth derived from the regression of the conversion of milk growth to actual growth (Appendix-2) are presented in Figure 3.14. As discussed in detail previously in this chapter, differences in both preweaning daily gain and 180 day weaning weight have been satisfactorly verified with data from The University Ranch.

3.4.9 Metabolizable Energy Input-Output

For the purpose of analysis of energy utilization, the reproductive cycle was divided into three periods: lactation, which lasted for 180 days, followed by a low pasture quality period which lasted for 60 days, and a wintering period which lasted for 100 days (a period of about 30 days from the end of the wintering to the next calving is not included, but only in the total).

Total simulated energy requirement, energy intake and the energy balance for the three periods, and from one calving to the next are given in Table 3.5. Yearly energy demand of **SY** cows was estimated to be greater than that of **HE** cows by 7.8%, but less than that of the **DY** cows by 3%. The **HE** cows were predicted to be the lowest in energy consumption followed by **DY** and **SY** by 7.4 and 8.6 percent, respectively. Energy demand in the first period was directly related to the energy requirements for milk production, thus the **DY** cow demanded 3.1 and 1.3 percent more energy than **HE** and **SY** cows, respectively. In the second and the third periods, energy demand was affected to a greater degree by pregnancy and maintenance requirements, so that the **SY** cows' demand for energy was at a rate similar to that of the **DY** cows, and the **HE** cows' demand was at a rate 5.5% less. This estimation indicated that **HE** cows tended to have lower wintering requirements than the other groups. Therefore, on a yearly basis the **HE** cows were estimated to just balance their energy budget, the **SY** cows accumulated some energy into their body reserve depot and the **DY** cows lost some energy reserve from body tissue.

These results are to some extent different from those reported by Bolduc *et al*. (1978). In their experiment they provided the cows with additional energy on days where the temperature was below -18°C. The amount of energy consumed in the winter by **HE**, **SY** and **DY** cows was 15.22, 15.22 and 15.20 Mcal/day compared to 13.90, 14.94 and 14.74 Mcal/day,

Table 3.5 Simulated total energy demand, energy in feed and energy balance over three seasonal periods and annualy in three breeding groups of cattle.

Item	Breeding Group	Period						Total	
		1		2		3			
		Mcal	Mcal/d	Mcal	Mcal/d	Mcal	Mcal/d	Mcal	Mcal/d
ENERGY DEMAND									
	HE	2871.5	15.93	3559.9	11.47	4950.5	13.90	5257.4	14.40
	SY	3156.2	17.53	3882.5	12.10	5376.5	14.99	5664.4	15.52
	DY	3252.3	18.07	3975.6	12.05	5459.7	14.74	5716.9	15.66
ENERGY IN FEED									
	HE	3119.9	17.33	3683.8	9.39	4984.7	13.00	5257.6	14.40
	SY	3485.0	19.36	4120.8	10.60	5492.8	13.72	5708.1	15.64
	DY	3439.0	19.10	4051.4	10.20	5408.5	13.57	5648.5	15.47
ENERGY BALANCE									
	HE	248.4	1.38	123.9	1.55	34.2	0.34	0.2	0.00
	SY	328.8	1.82	238.3	2.97	116.2	1.16	44.1	0.12
	DY	186.7	1.03	75.8	0.94	-41.2	-0.41	-68.4	-0.19

respectively, simulated in this study. Based on that, it was concluded in their study that the winter maintenance requirements of **HE**, **SY** and **DY** cows were: 12.64, 12.59 and 12.62 Mcal/day compared to the prediction of 11.05, 11.90 and 11.8 Mcal/day, respectively.

The average daily energy used for maintenance in the whole period from calving to calving by **HE**, **SY** and **DY** cows was predicted to be 9.86, 10.57 and 10.46 Mcal/day, respectively. Heat production was 12.12, 13.28 and 12.74, and the additional heat produced in the winter to maintain normal body temperatures was 0.23, 0.24 and 0.19 in 1976 and 0.37, 0.45 and 0.41 Mcal/day in 1977, respectively.

The simulated energy balance of the cow expressed in Mcal of ME/day for the three groups is shown in Figure 3.15. When compared to the **VFI** pattern shown in Figure 3.9, the energy balance, which represented the difference between cow energy intake and energy demand, showed a very similar pattern. A positive balance of about 1 to 3 Mcal/day for the period May through August, and a fluctuating balance for the rest of the time were simulated. This fluctuation in energy balance was derived from the nature of the relationship between energy intake and energy demand (Figure 3.16).

Increase in energy demand immediately after parturition early in April, could not be compensated by energy intake (due to low early pasture availability and upper limit on feed intake), and a negative balance was predicted. By mid May, energy consumption equalled demand, and a balanced energy exchange was predicted. From there onwards increase in pasture energy concentration and intake, and a reduction in energy demand for milk resulted in positive balance. In mid-September two things happened, pasture became less concentrated energetically and calves were weaned. Consequently, both energy in the feed and energy demand were on the decline. In November due to a decrease in ambient temperature, an increase in energy demand for maintenance with no change in energy in the feed was predicted, which resulted in a negative energy balance. In December, a supplementary feeding system was introduced and energy in the feed was increased towards balancing winter energy requirements. The supplementary feeding plan which was practiced at The University Ranch did not provide the total amount of energy needed by the cows in the period January to February, thus, the estimated balance tended to be slightly negative. In March, there was an increase in energy demand due to an increase in fetal energy requirements, accompanied by a slight decrease in energy intake (due to fetal volume (Forbes, 1977)). Therefore, a negative balance was predicted for this period.

3.4.10 Wintering

Within the thermoneutral zone, heat production for a given feed intake is constant (Webster 1978), (Figures 3.9 and 3.17). Below the thermoneutral zone, heat production is increased, and this can only occur if energy is diverted from productive purposes. It is therefore of practical importance that the limits of the thermoneutral zone be defined. Since the temperatures in Alberta can drop below the thermoneutral zone in the winter, but very rarely can increase above it, only the cow's lower critical temperature (Tc) was simulated. Figure 3.18 shows the simulated lower critical temperature in the three groups as affected by the change in cow energy balance (Figure 3.15).

It was shown in several studies (Bruce and Clark, 1979; Webster 1978; Young, 1981), that the level of energy intake is directly related to the lower critical temperature. When feed intake was high (May to September) the predicted lower critical temperature tended to be very low, about -30°C (Figure 3.18). This value was similar to that reported for beef cattle by Webster (1978). For the period September to December where intake and digestibility were fairly low, the predicted lower critical temperature was relatively high (above 0°C). These values were calculated on the assumption that the internal insulation factor is a function of weight and not of reserves. Since in this period body reserves are at their highest level, it is expected that cow insulation would be better and critical temperature would be lower. However, this can be considered as the only period where heat losses in relatively comfortable weather can induce increases in energy input into heat production. In December, when higher quality supplementary feed was provided to the cows, the lower critical temperature dropped to a level of

-10°C, which still was not low enough to resist the fairly low ambient temperatures existing at that time, and cows were predicted to catabolize fat to keep body temperature stable.

Differences among group were estimated to be small. The **HE** cows because of their lower intake usually presented an inferior critical limit at higher ambient temperatures.

3.4.11 Body Reserve

The principle of degree of maturity was introduced in the Texas A&M model (Sanders, 1977). In the present model, by contrast a concept of body reserve was introduced and used in the computation of fairly similar control variables. The simulated pattern of the body reserve depot as a percentage of empty body weight in the three groups for the two years 1976-77 is shown in Figure 3.19. Immediately after parturition, there was a decline in body reserve which contributed to the corresponding drop in cow weight after calving. About 40 to 60 days after parturition when energy balance was improved, there was an increase in body reserve which continued till September when pasture limitation imposed a negative balance. Thus, from thereafter, body reserve was predicted to decrease.

Breeding group differences did not show the same pattern over the years. While in 1976 **HE** and **SY** cows presented the same body reserve proportion, in 1977 the **DY** and **SY** cows were predicted to be very similar. A similar pattern was reported by Bolduc *et al*. (1978) for the same two years using ultrasonic measurement of backfat changes over the trial period as shown in Figure 3.20.

To compare these predictions with Bolduc's results, the histograms shown in Figure 3.21 were drawn. Despite the similarities in relative proportions among groups, the difference between the years did not show the same magnitude. While 1976 was a better year in Bolduc's trial, 1977 was simulated to be a better year in this study. The reason for it, may rest with the initialization of parameters in 1976 which were based on literature estimates. The reason for the change which was simulated for the **SY** cows between the years can probably be explained by the decrease in the relative energy intake of this group in response to the lipostatic mechanism in July-August (as explained in detail in the section on dry matter intake).

3.4.12 Grazing

Since pasture availability in this model was used only as a dynamic auxillary variable, it did not have the usual flexibility normally found in simulation grazing models. Increase in pasture biomass was described as a fixed exponential Brody-type function with parameters obtained from analysis of local data (Bailey *et al*. 1978). The simulated pattern of the biomass removal from each acre of pasture, was predicted to have a sigmoid shape as shown in Figure 3.22. The residual biomass is represented by the area between the production and the consumption curves. As discussed before in the first year, SY cows were estimated to consume more pasture than DY and both much more than the HE.

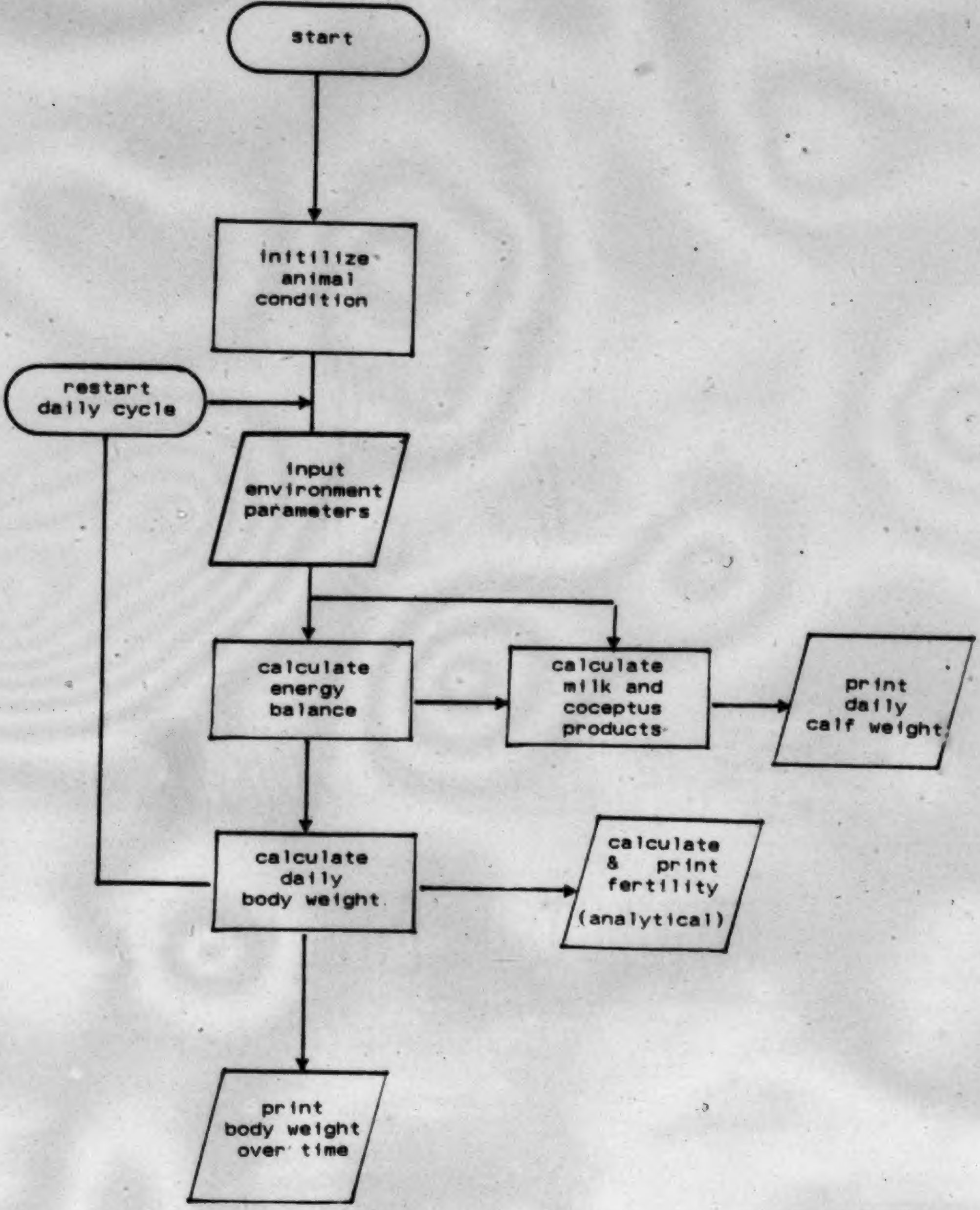
start
initilize animal condition
restart daily cycle
input environment parameters
calculate energy balance
calculate milk and coceptus products
print daily calf weight
calculate daily body weight
calculate & print fertility (analytical)
print body weight over time

Figure 3.1 Outline of model components used to estimate daily changes in output variables

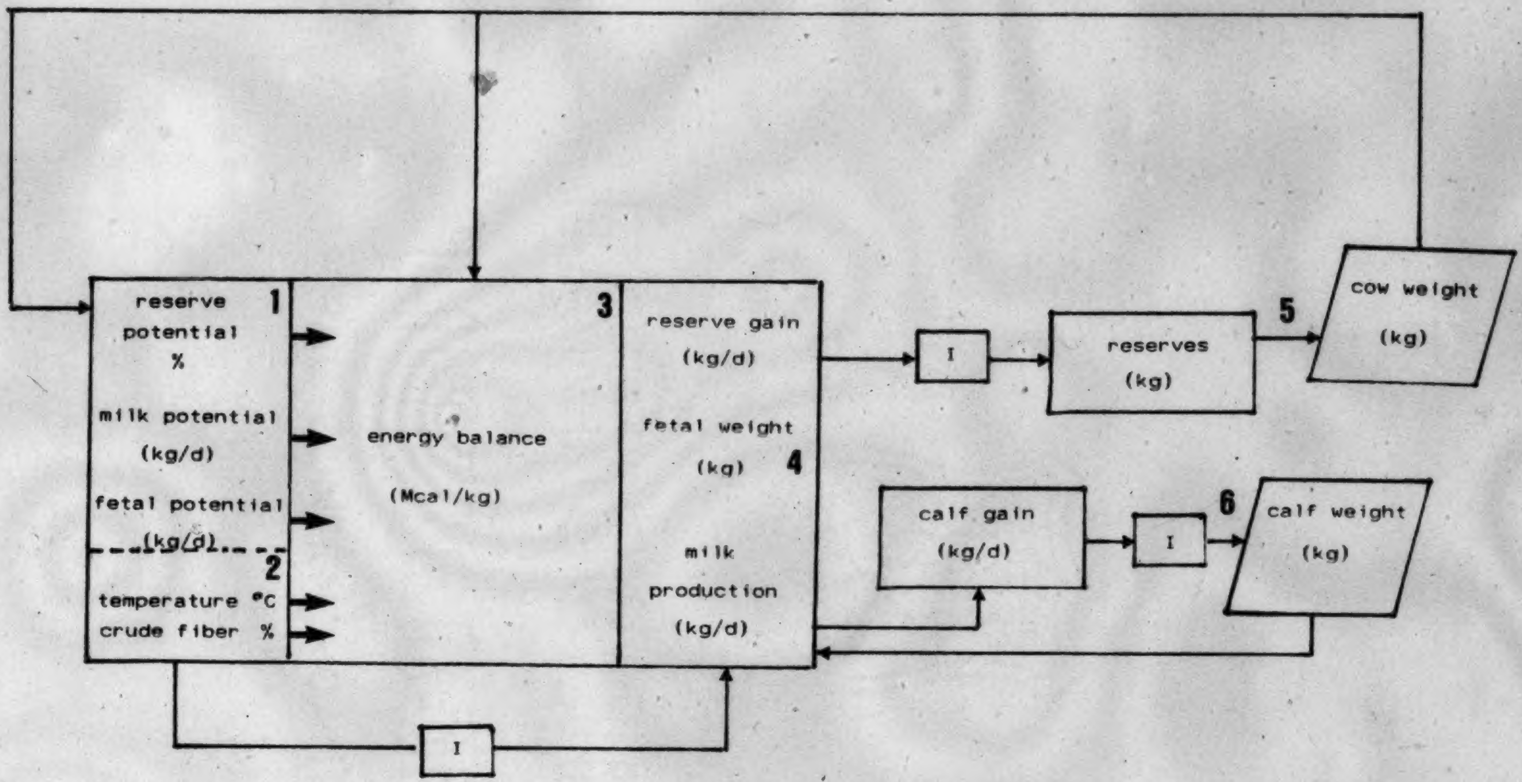
reserve potential %
1
milk potential (kg/d)
fetal potential (kg/d)
2
temperature °C
crude fiber %
3
energy balance (Mcal/kg)
reserve gain (kg/d)
fetal weight (kg)
4
milk production (kg/d)
I
reserves (kg)
5
cow weight (kg)
calf gain (kg/d)
I
6
calf weight (kg)
I

Figure 3.2 Block diagram of the model COW.82 used to simulate cow weight and calf weight (the numbers 1 to 6 represent the different sections; the (I) represents a step of integration)

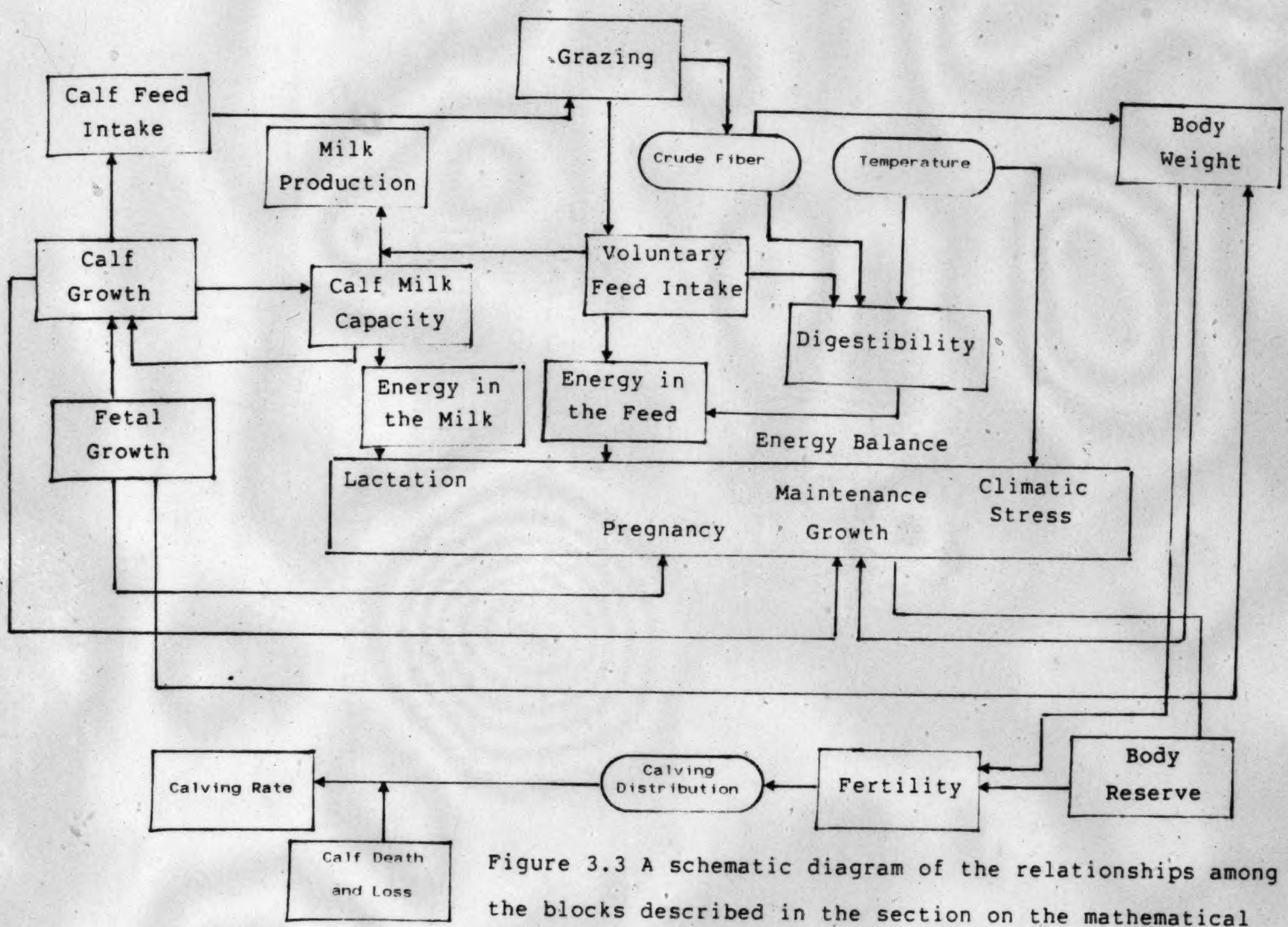
Grazing
Calf Feed Intake
Milk Production
Crude Fiber
Temperature
Body Weight
Calf Growth
Calf Milk Capacity
Voluntary Feed Intake
Digestibility
Energy in the Milk
Energy in the Feed
Energy Balance
Fetal Growth
Lactation
Maintenance
Climatic Stress
Pregnancy
Growth
Body Reserve
Fertility
Calving Distribution
Calving Rate
Calf Death and Loss

Figure 3.3 A schematic diagram of the relationships among the blocks described in the section on the mathematical structure of the model

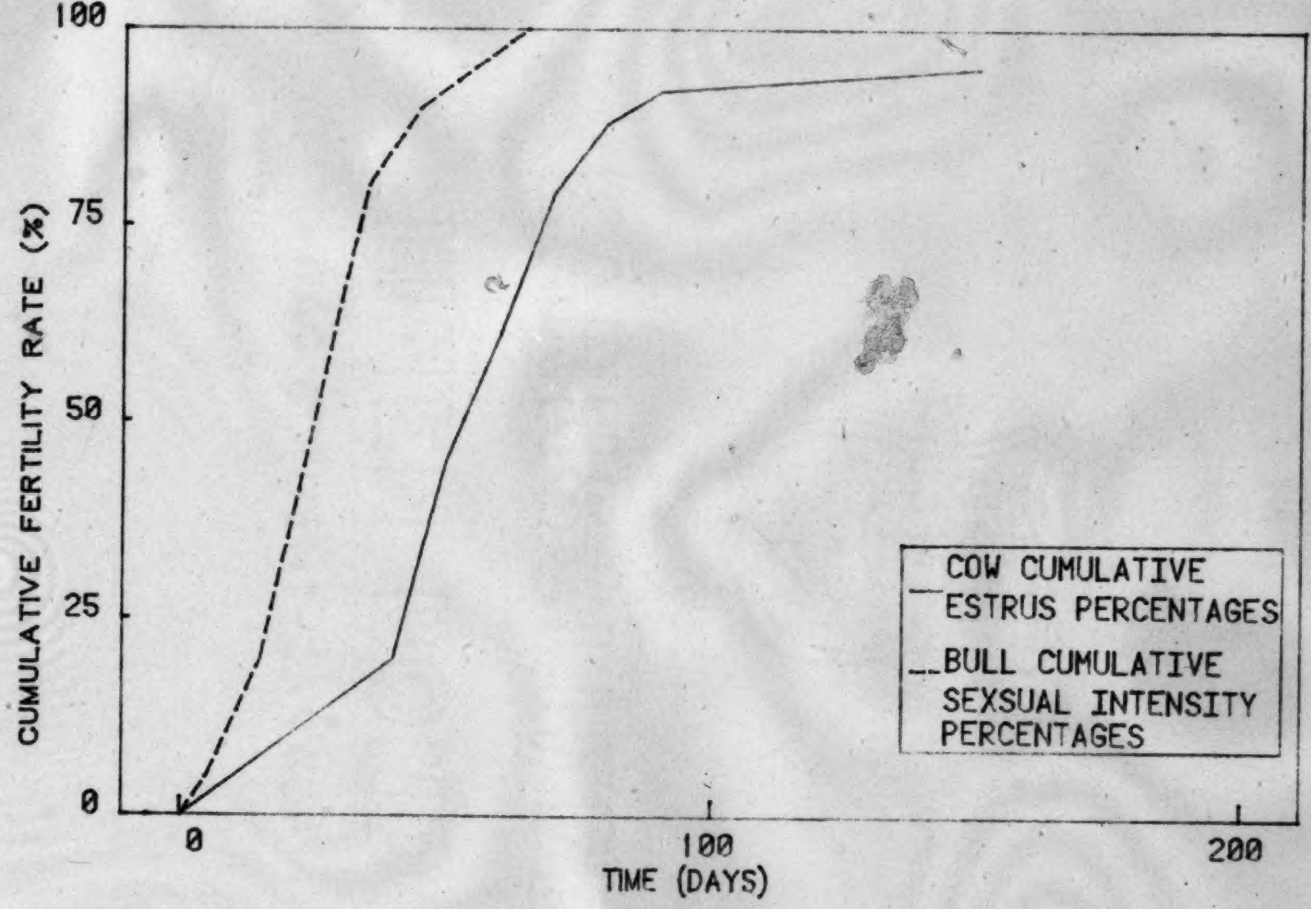

Figure 3.4 Fertility of range beef cattle during the breeding season

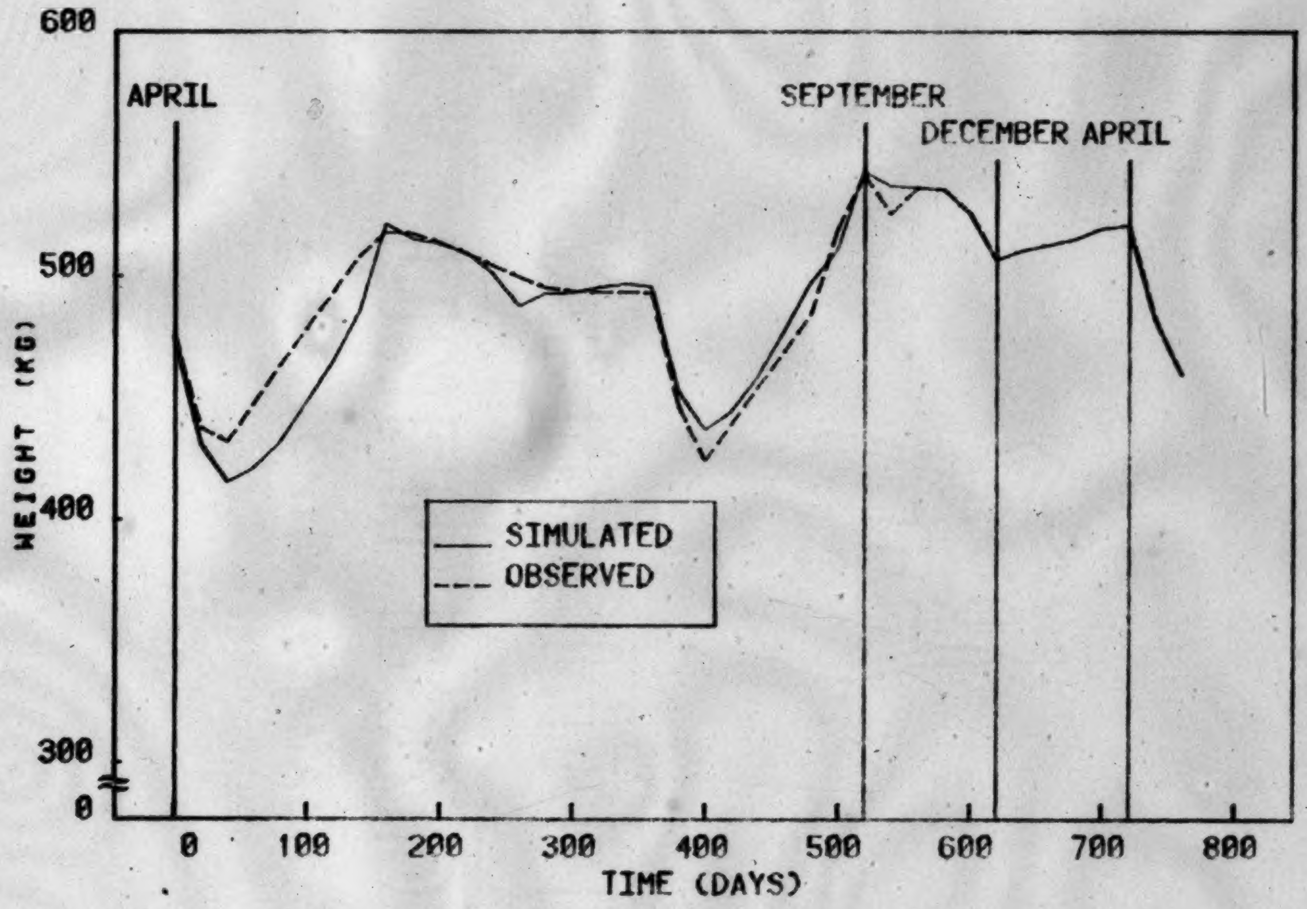

Figure 3.5 Validation of simulated weight in Hereford cows

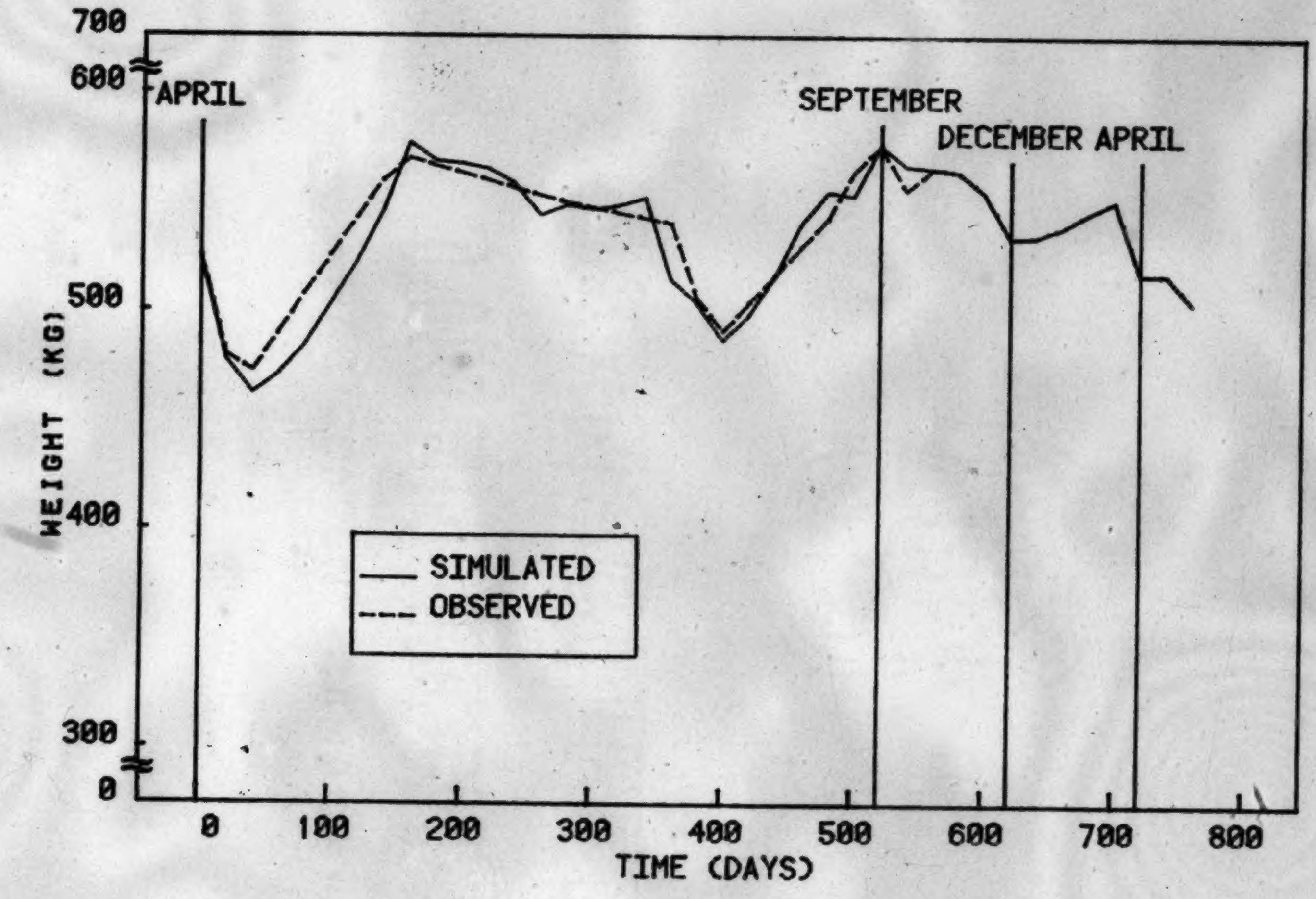

Figure 3.6 Validation of simulated weight in Beef Synthetic cows

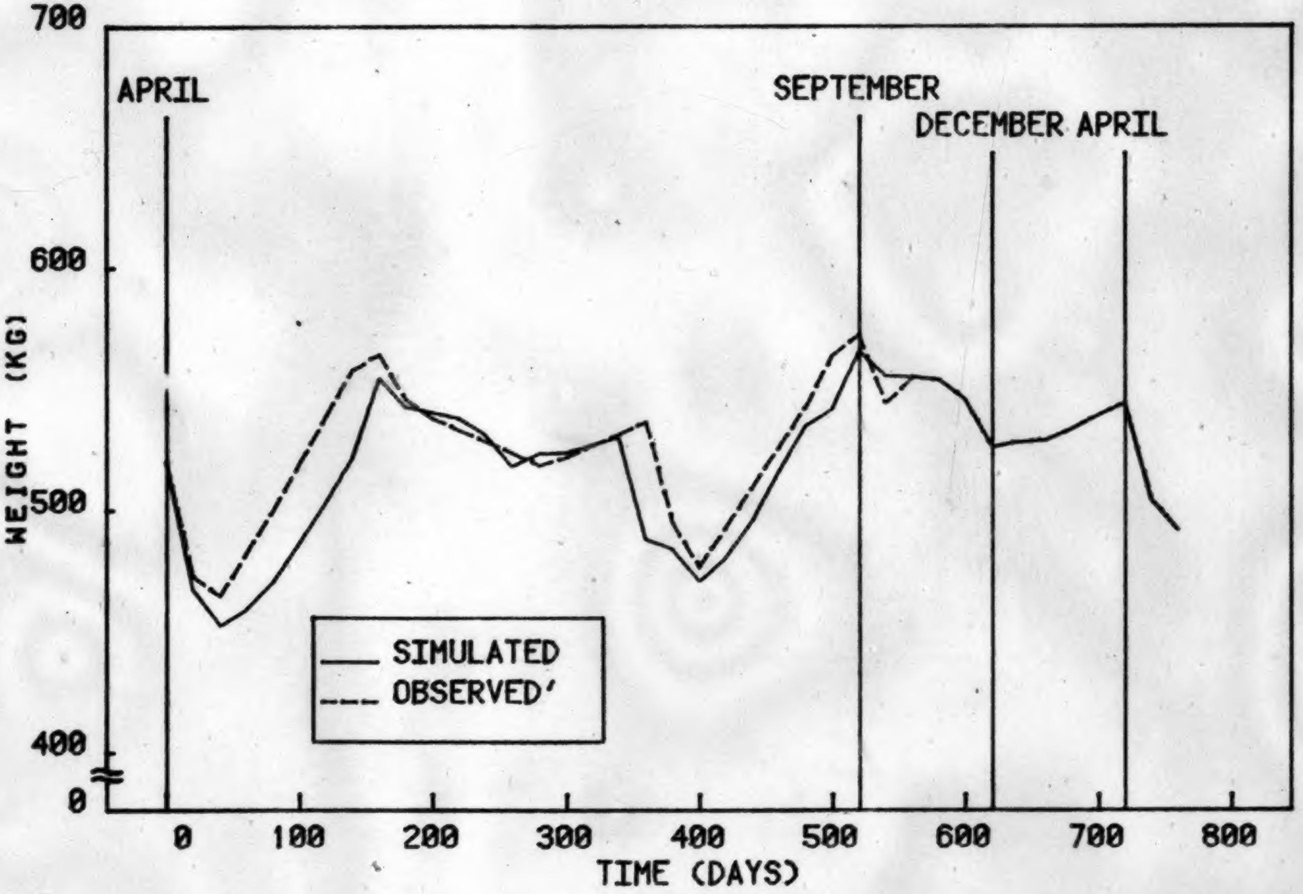

Figure 3.7 Validation of simulated weight in Dairy Synthetic cows

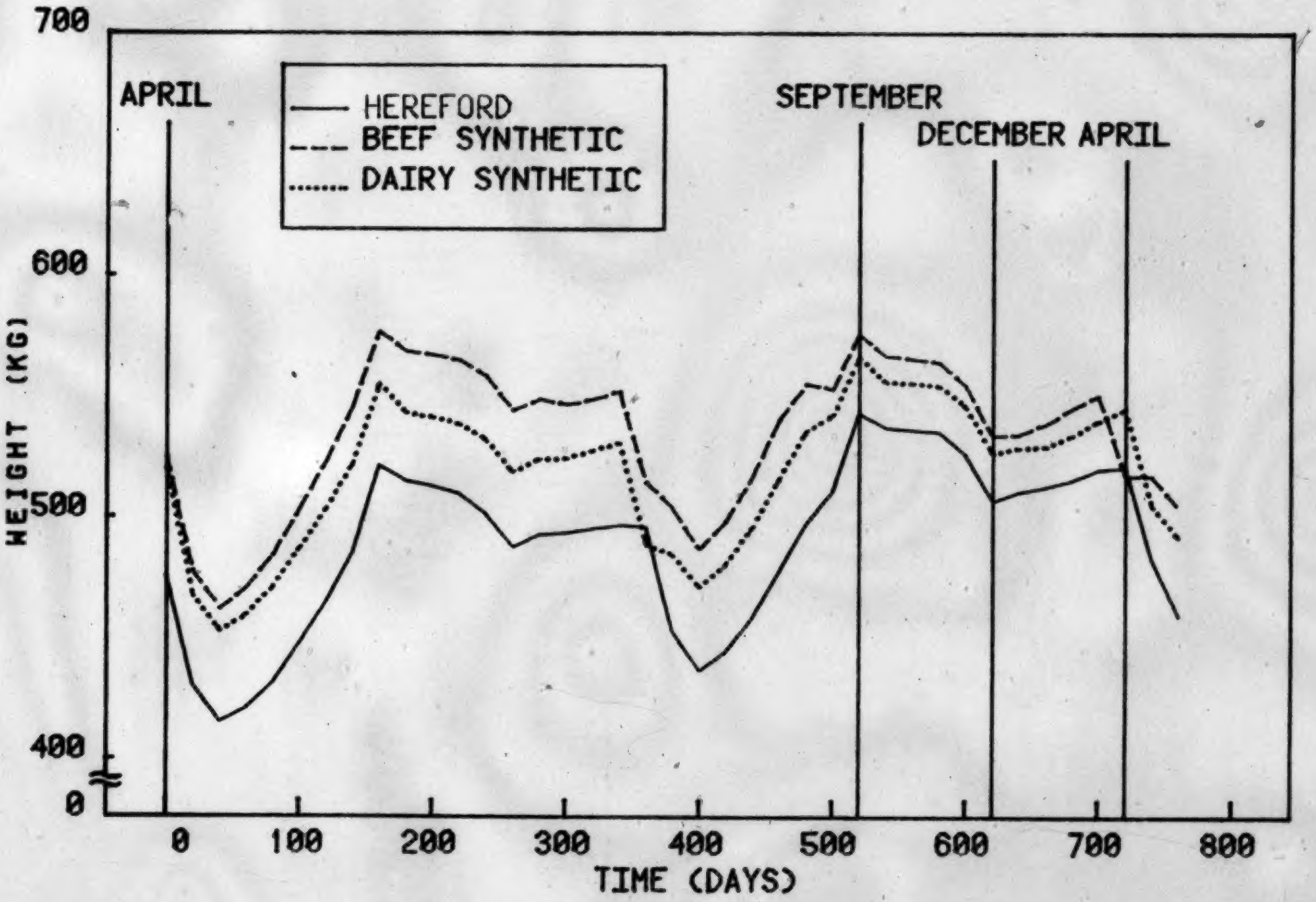

Figure 3.8 Simulated live weight of cows from three lines

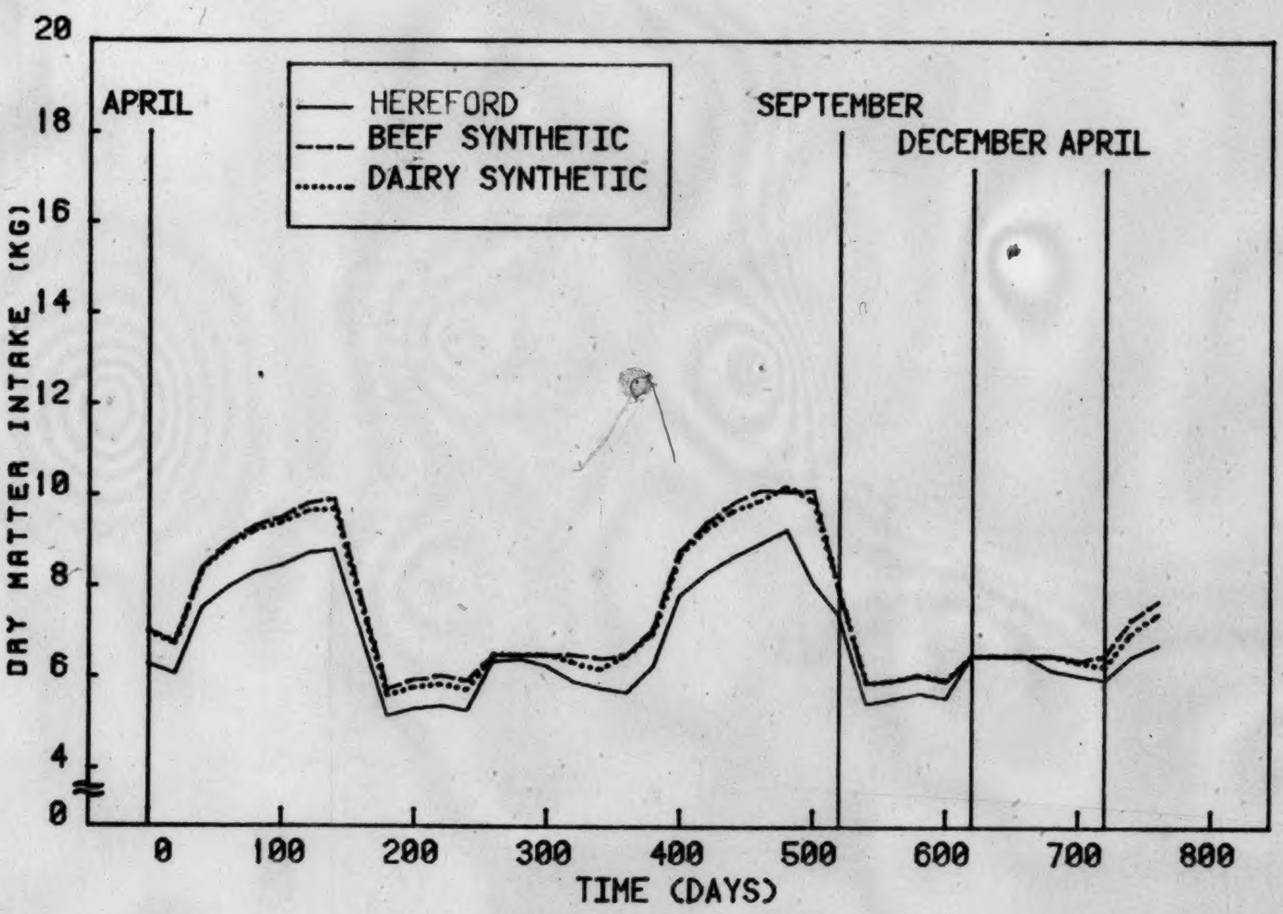

Figure 3.9 Simulated dry matter intake of cows from three lines

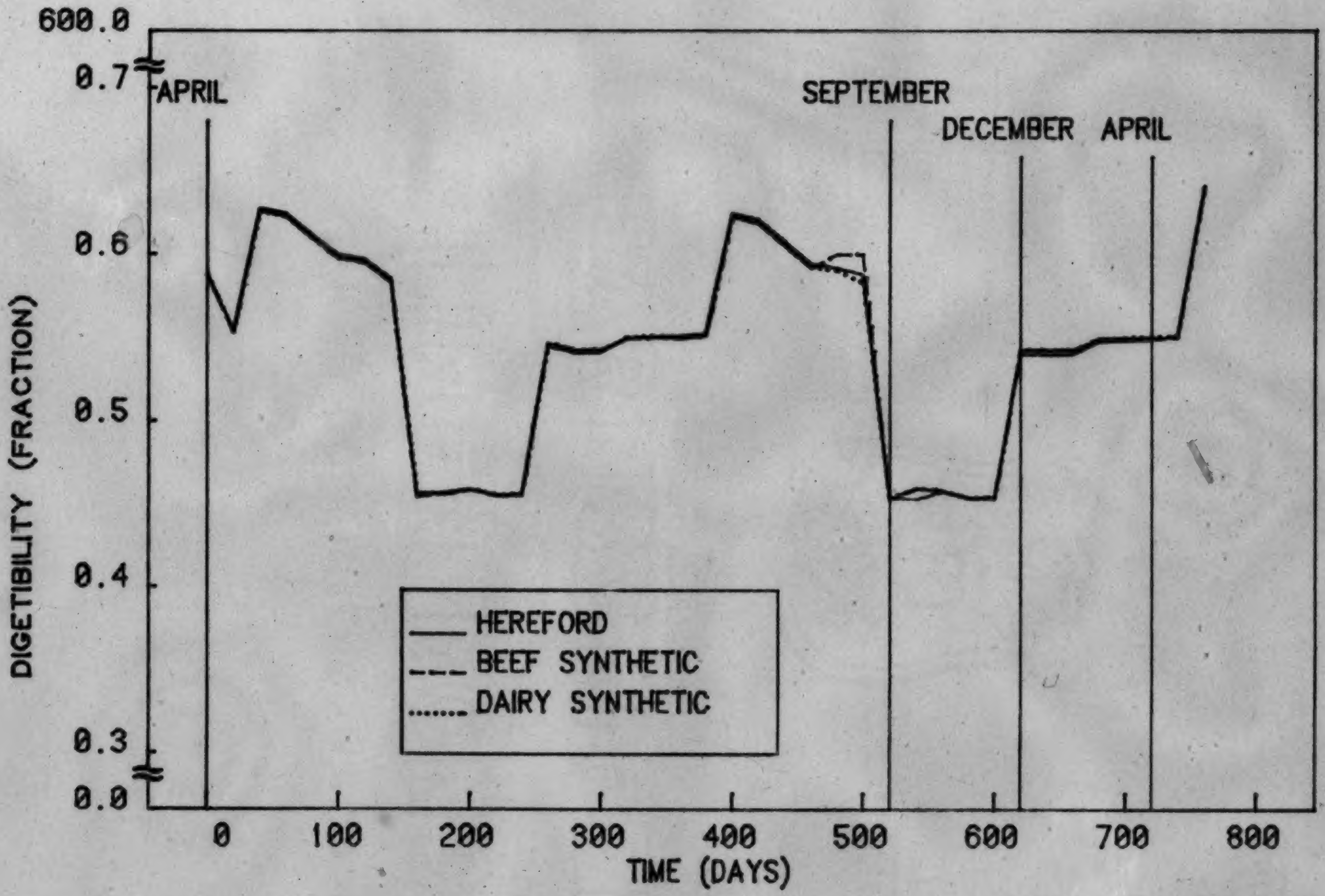

Figure 3.10 Simulated feed digestibilty by cows from three lines

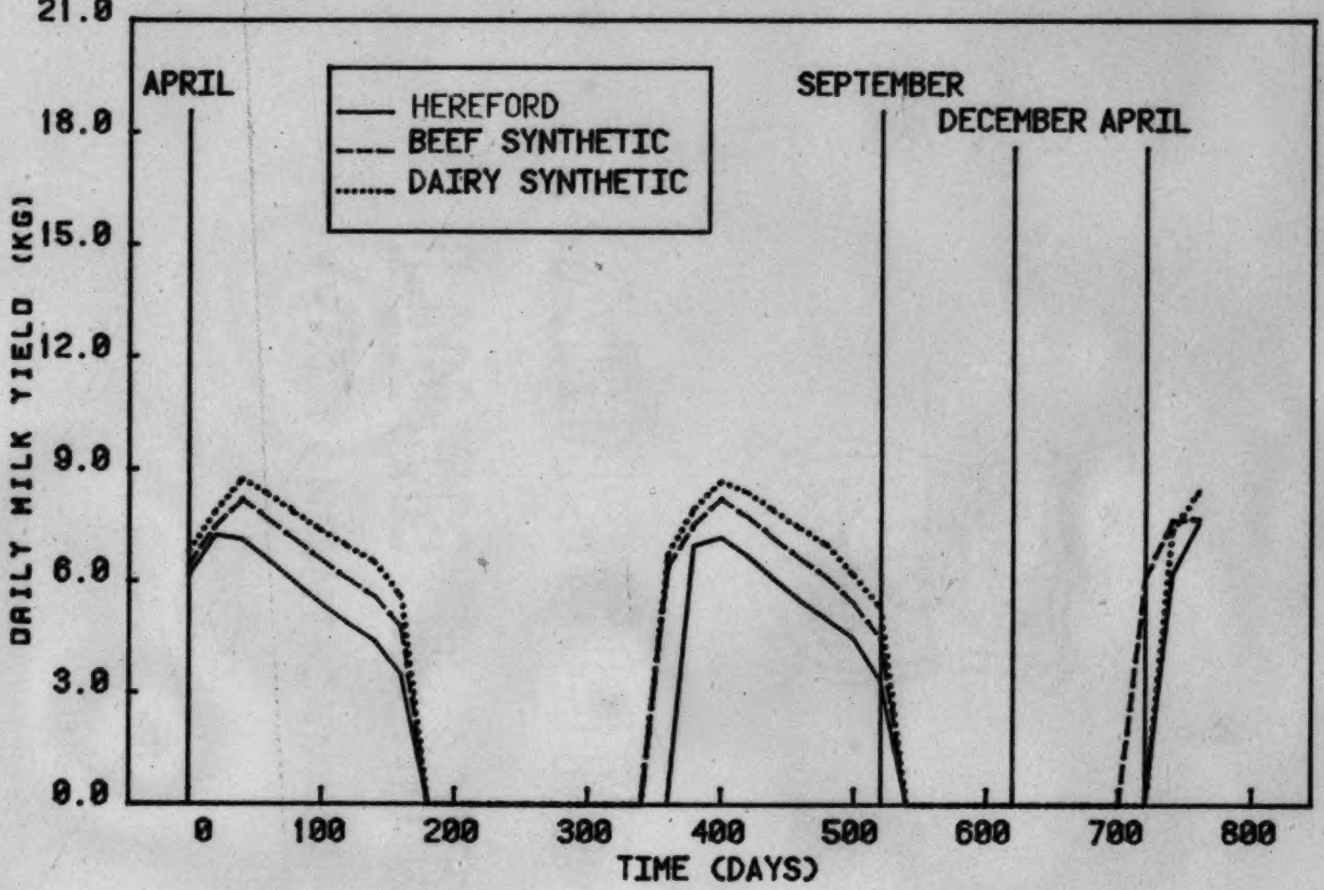

Figure 3.11 Simulated milk yield of cows from three lines

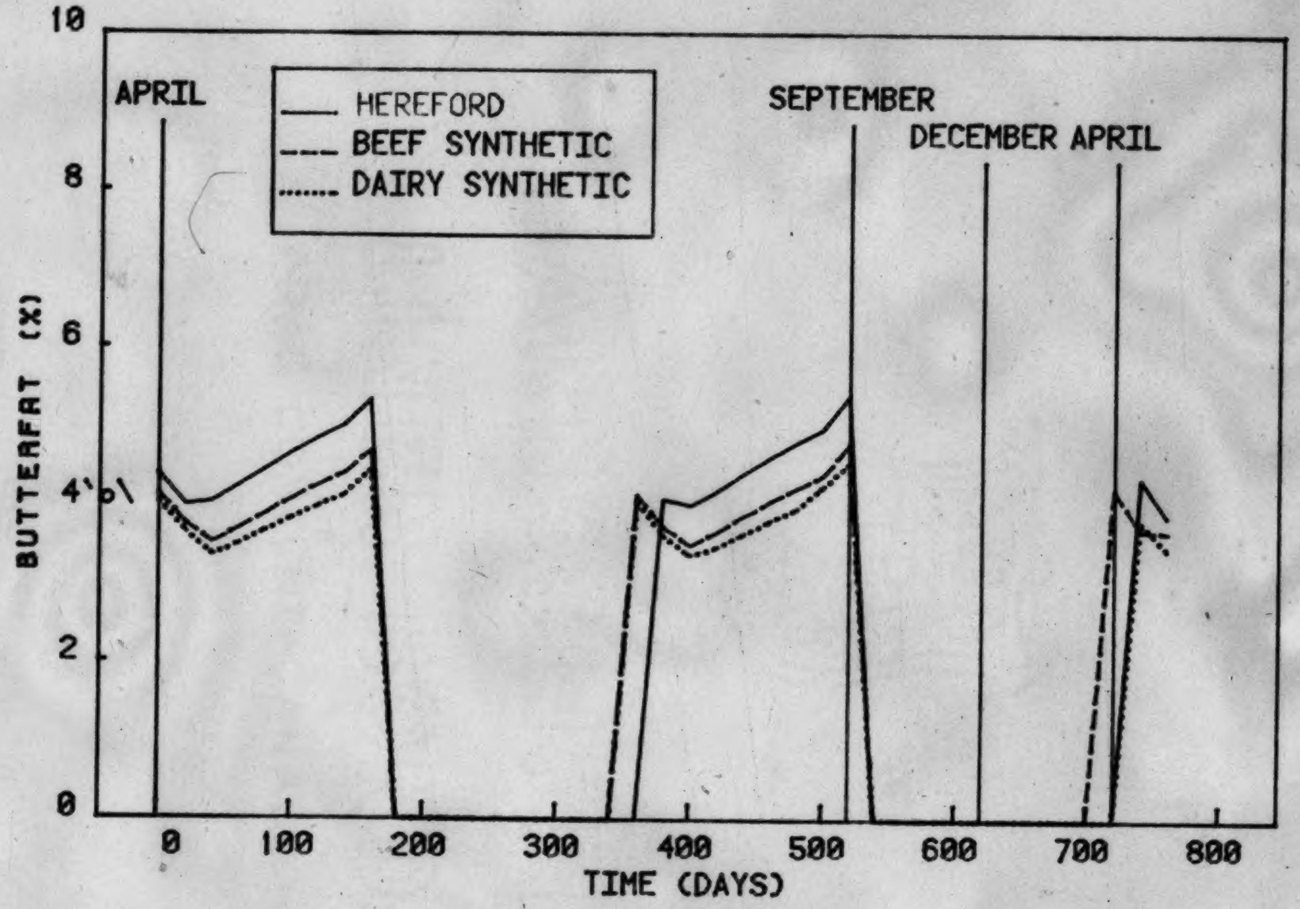

Figure 3.12 Simulated butterfat in the milk of cows from three lines

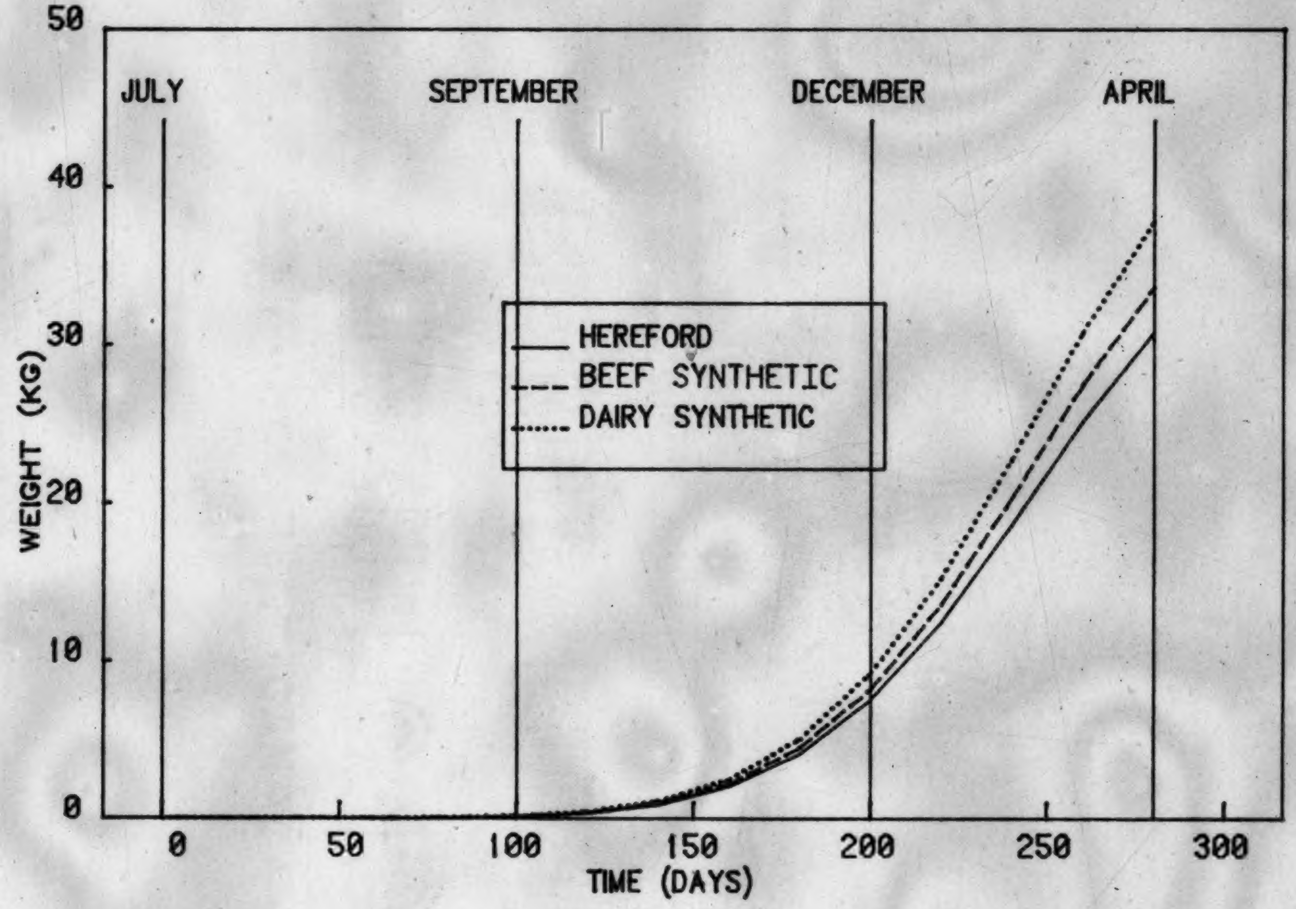

Figure 3.13 Simulated fetal growth of calves from three lines

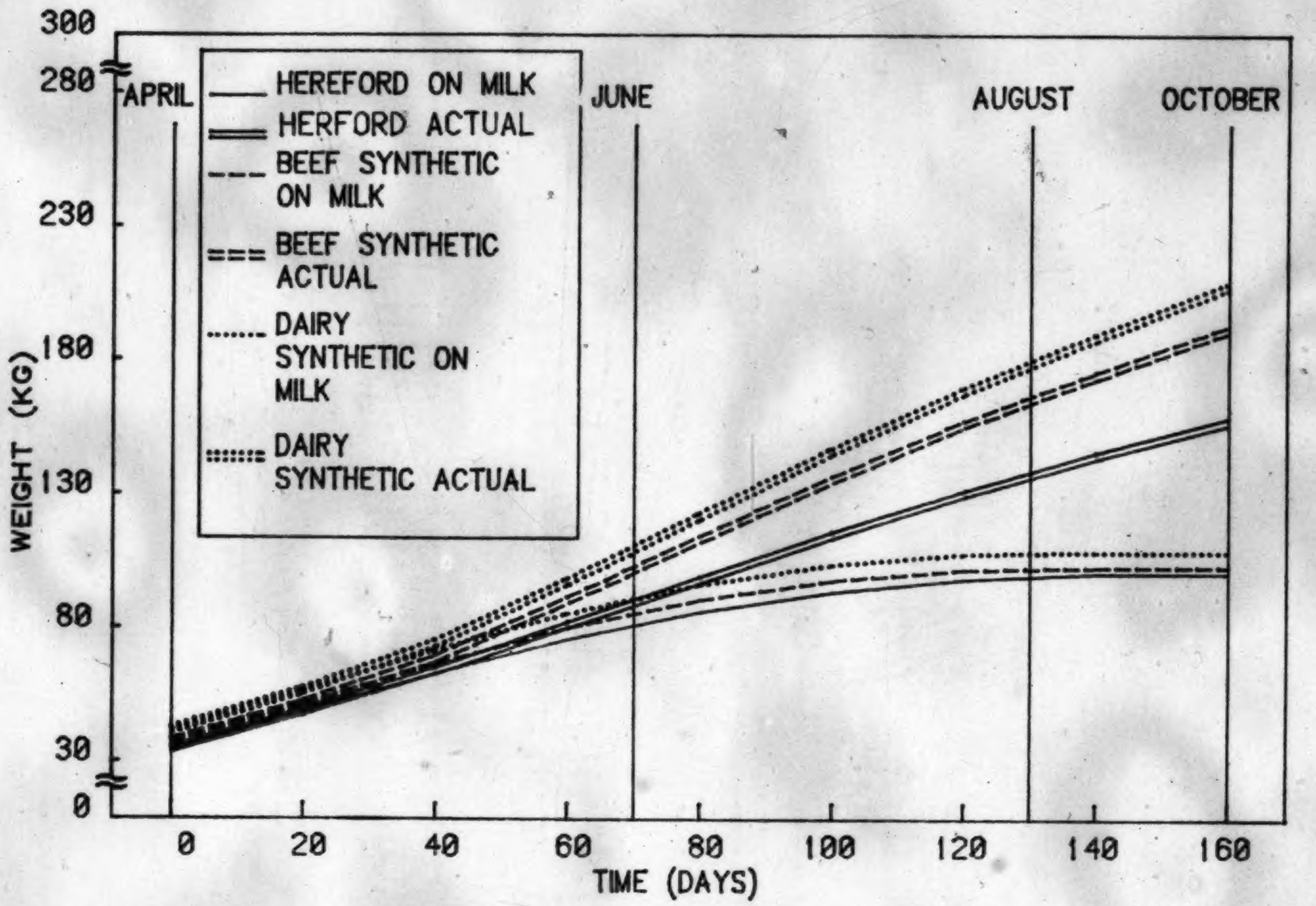

Figure 3.14 Simulated preweaning growth of calves from three lines

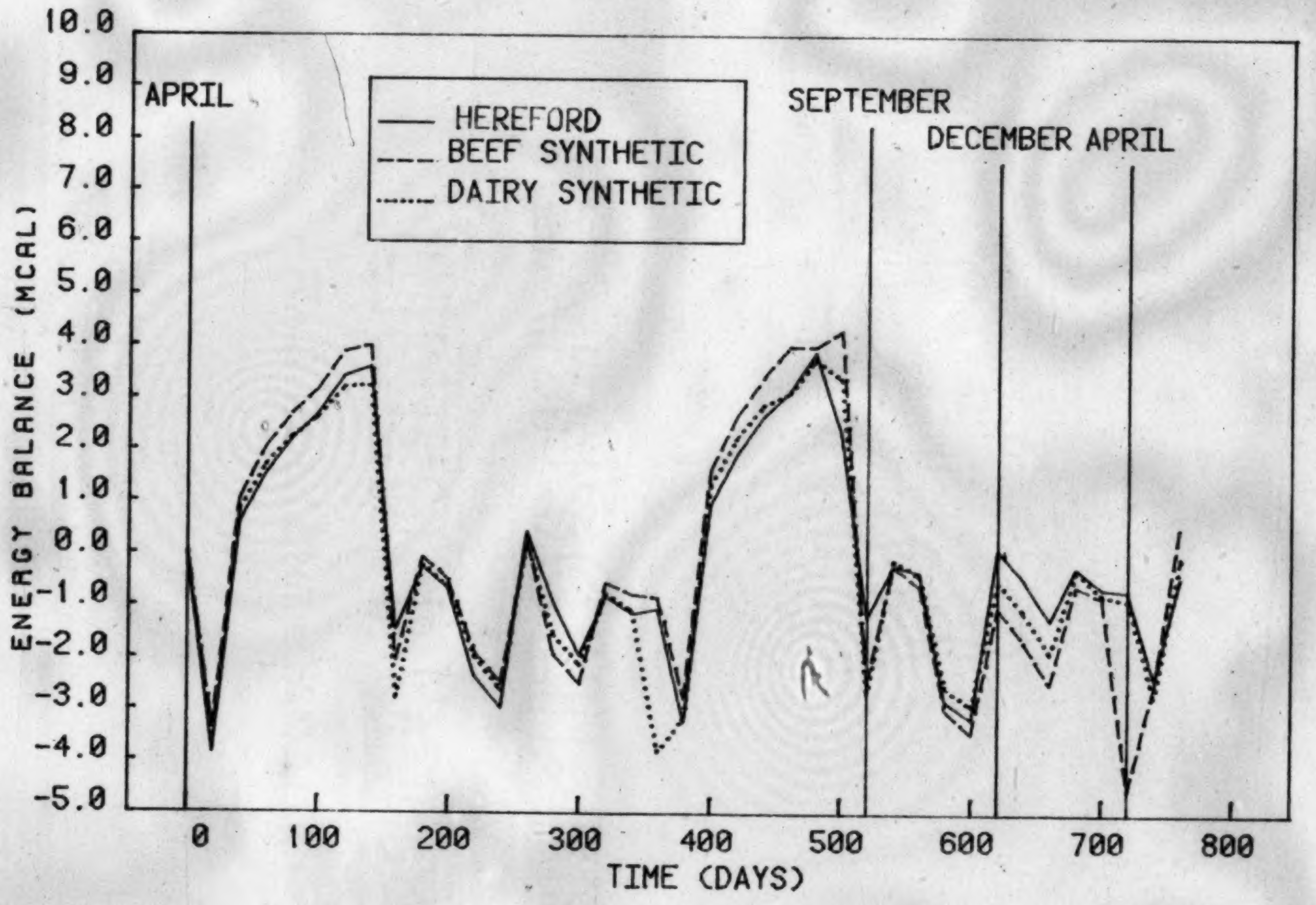

Figure 3.15 Simulated body energy balance of cows from three lines

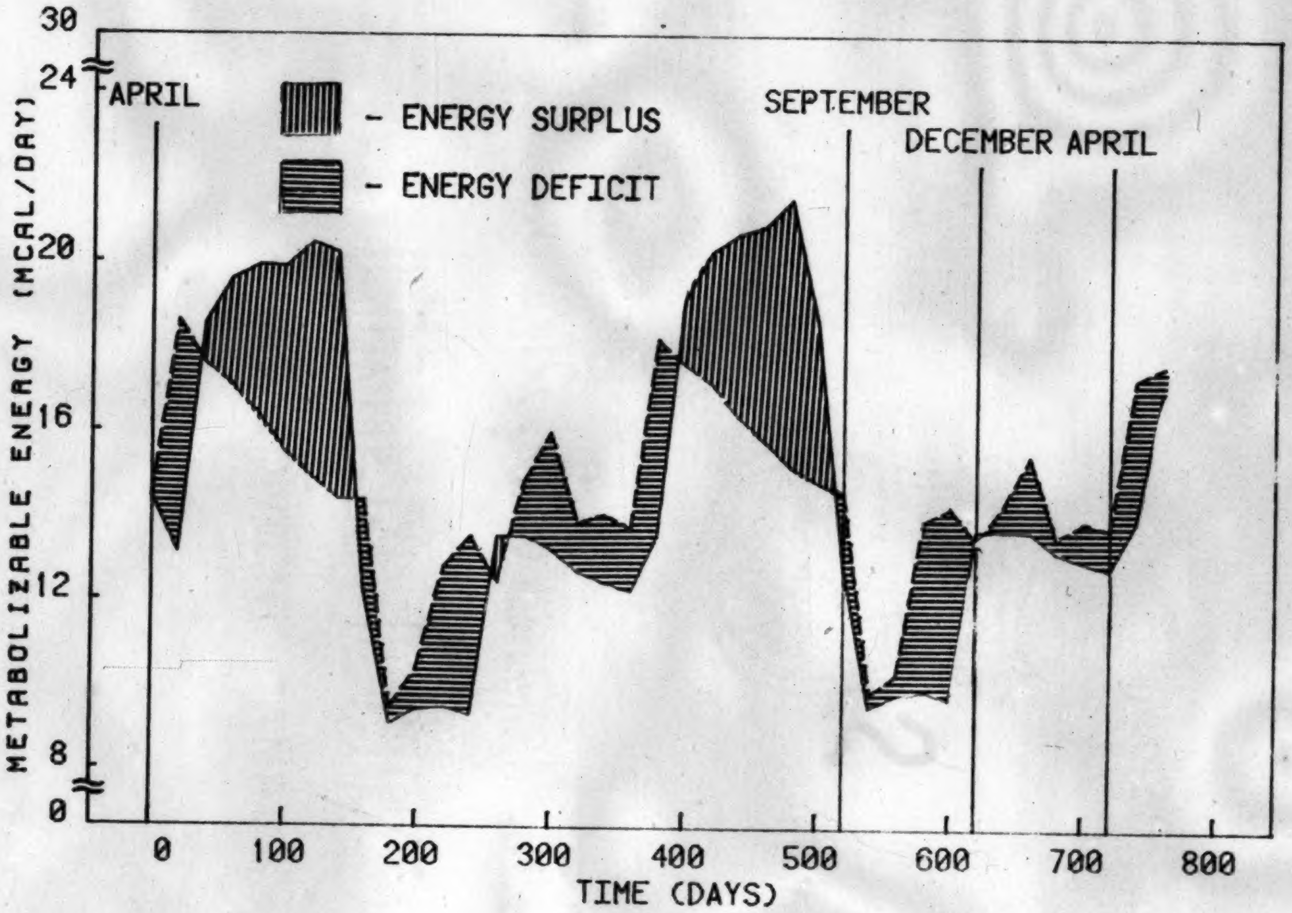

Figure 3.16 Simulated energy input-output in beef cows

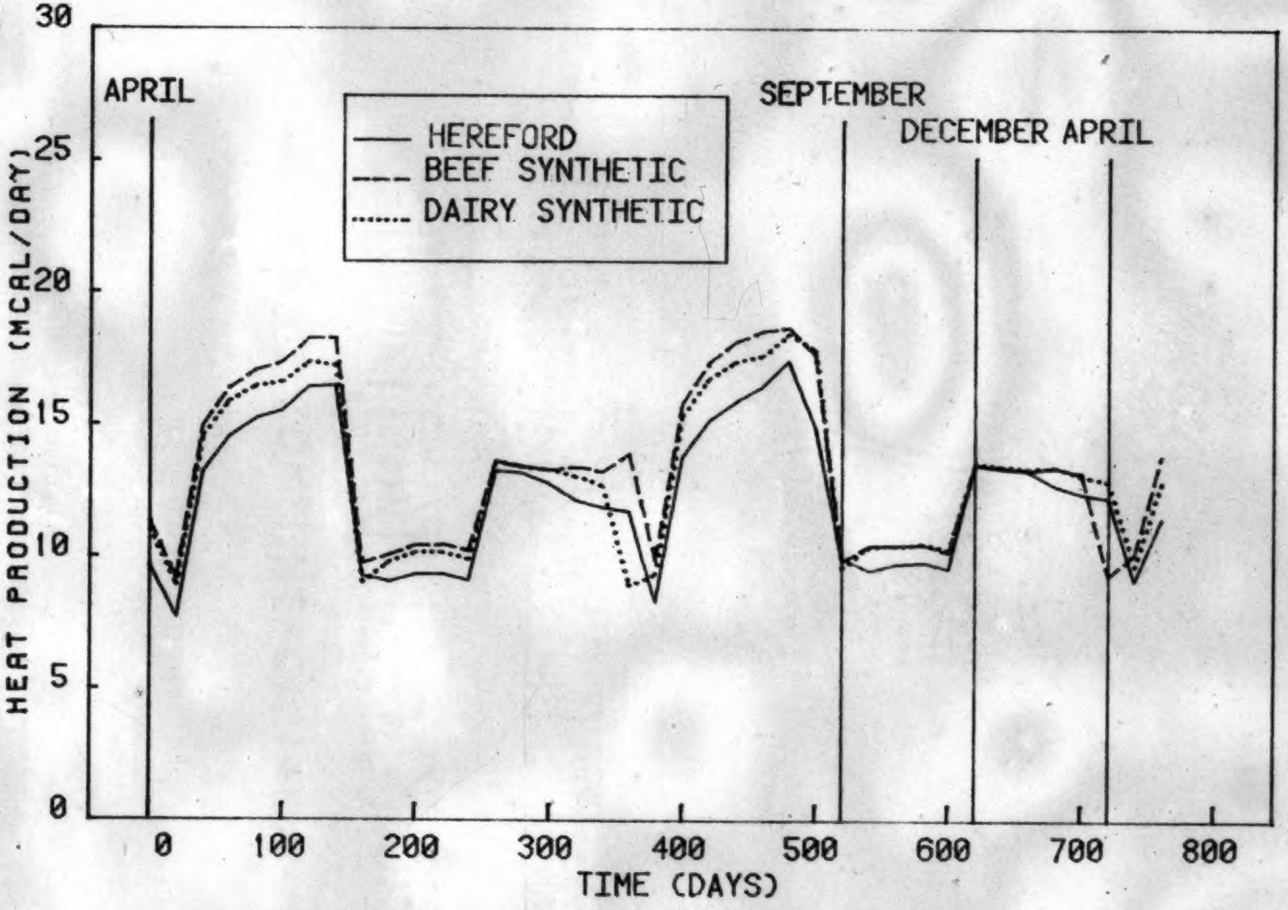

Figure 3.17 Simulated heat production within the thermoneutral zone of cows from three lines

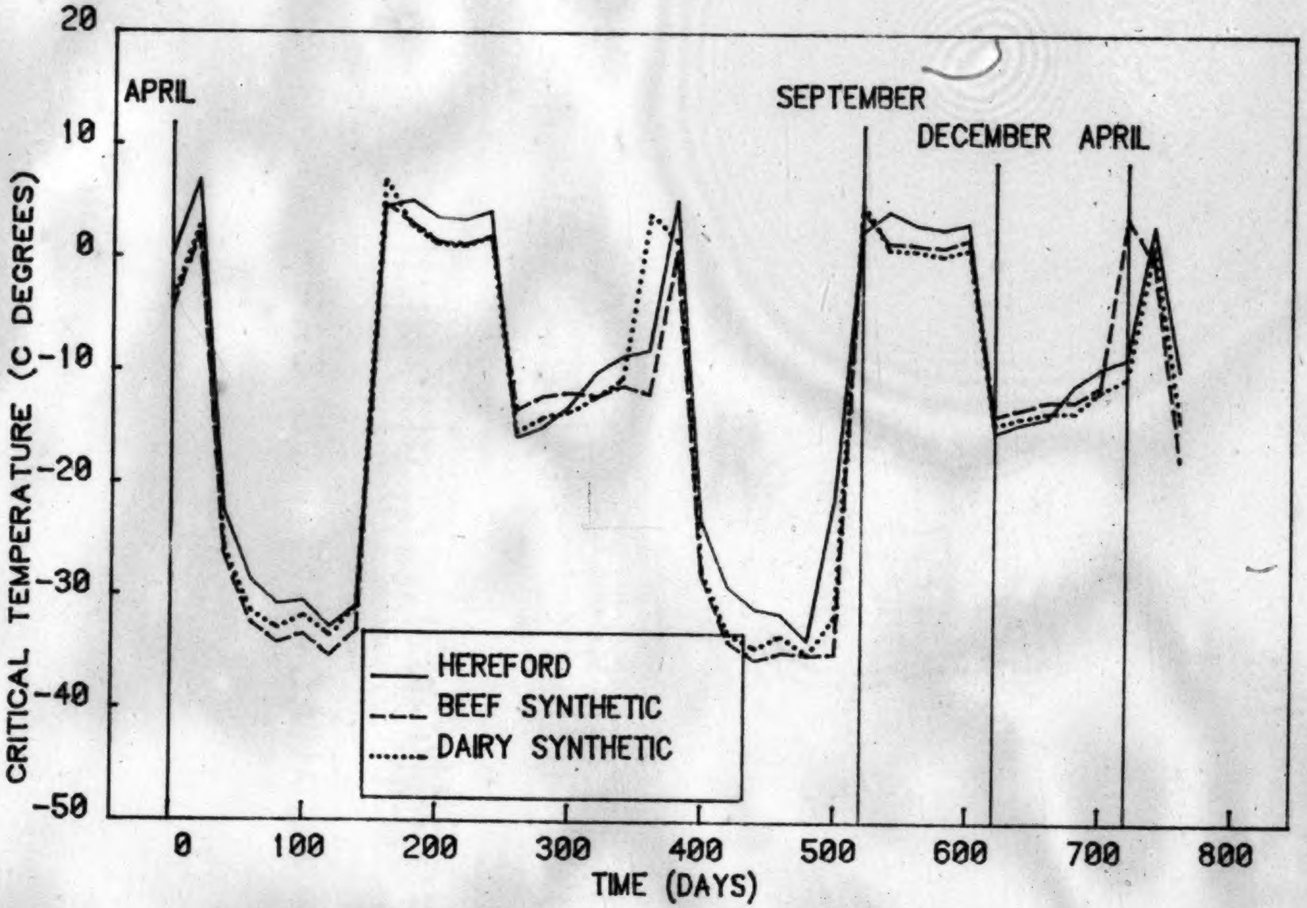

Figure 3.18 Simulated lower critical temperature of cows from three lines

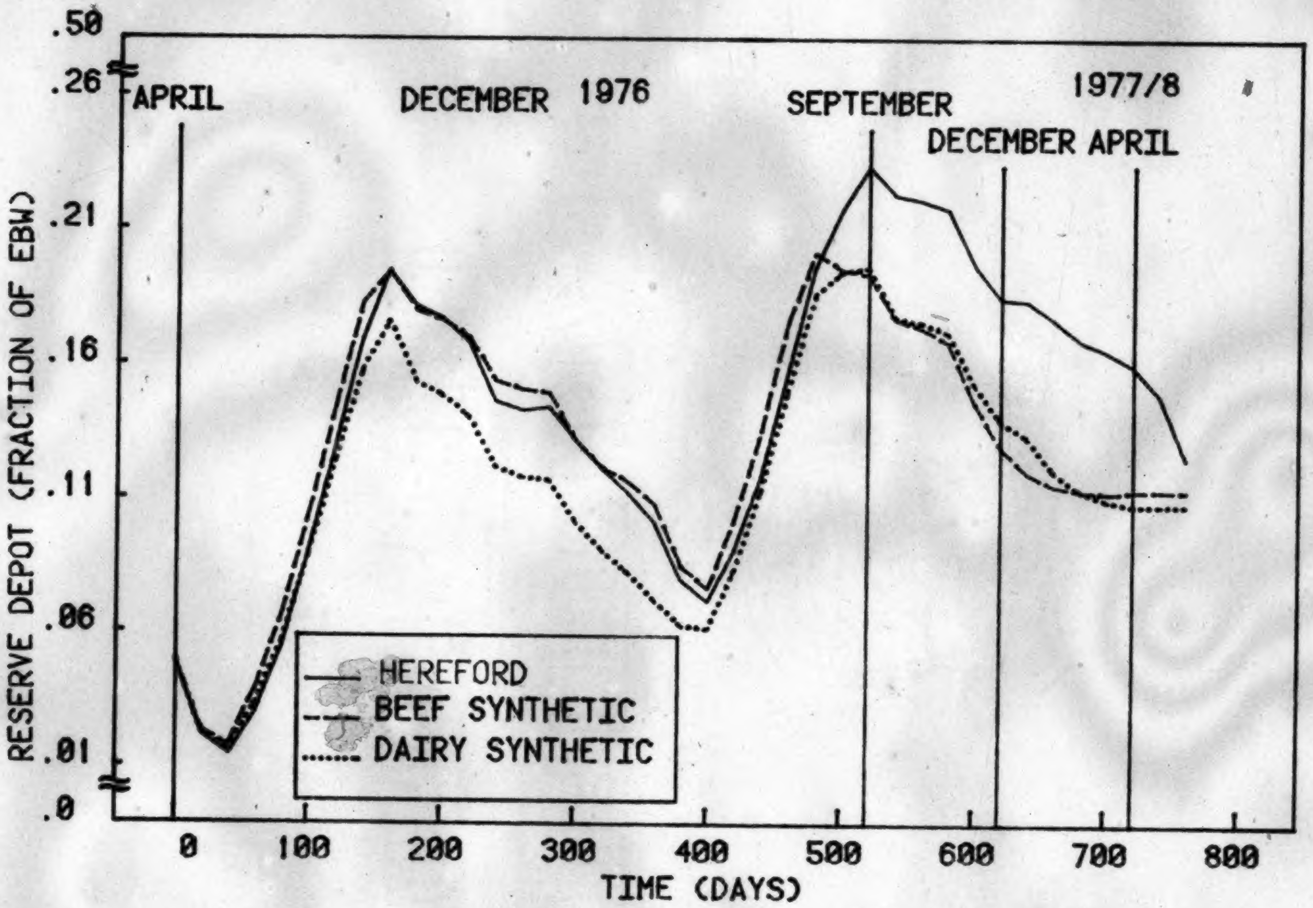

Figure 3.19 Simulated body reserve depot of cows from three lines

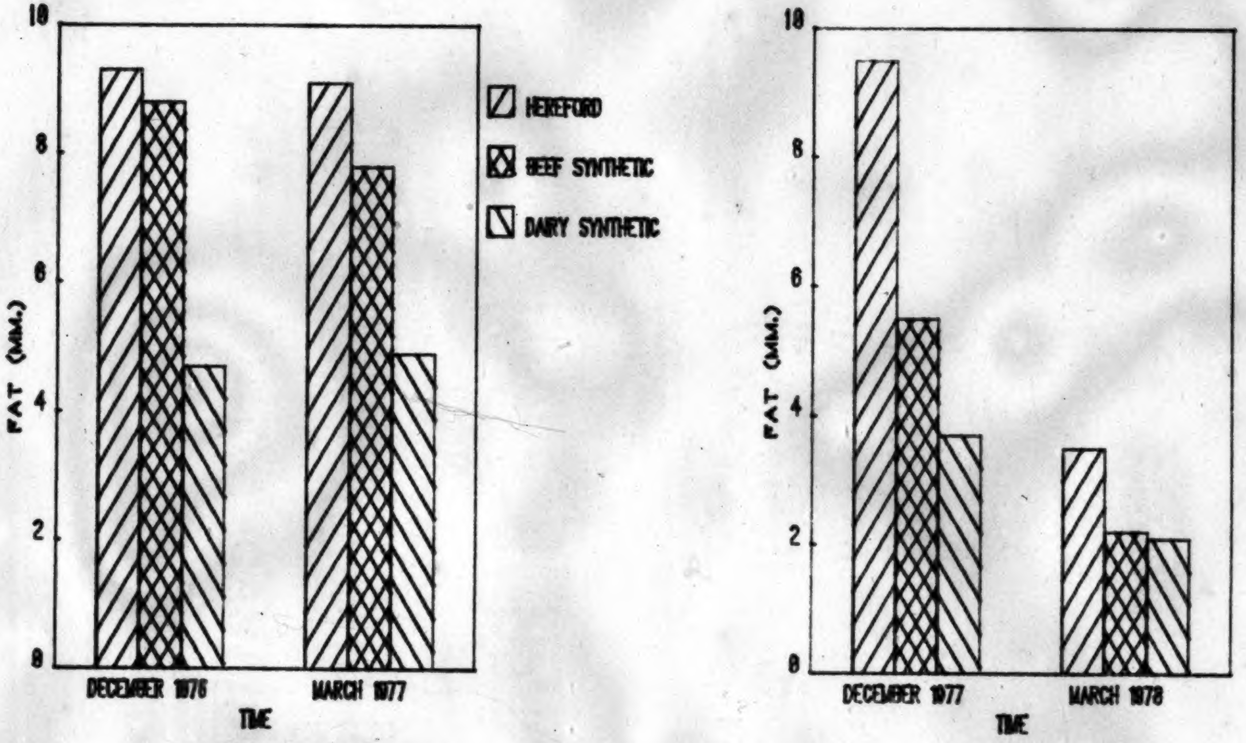

Figure 3.20 Average ultrasonic fat measurement in cows from three lines

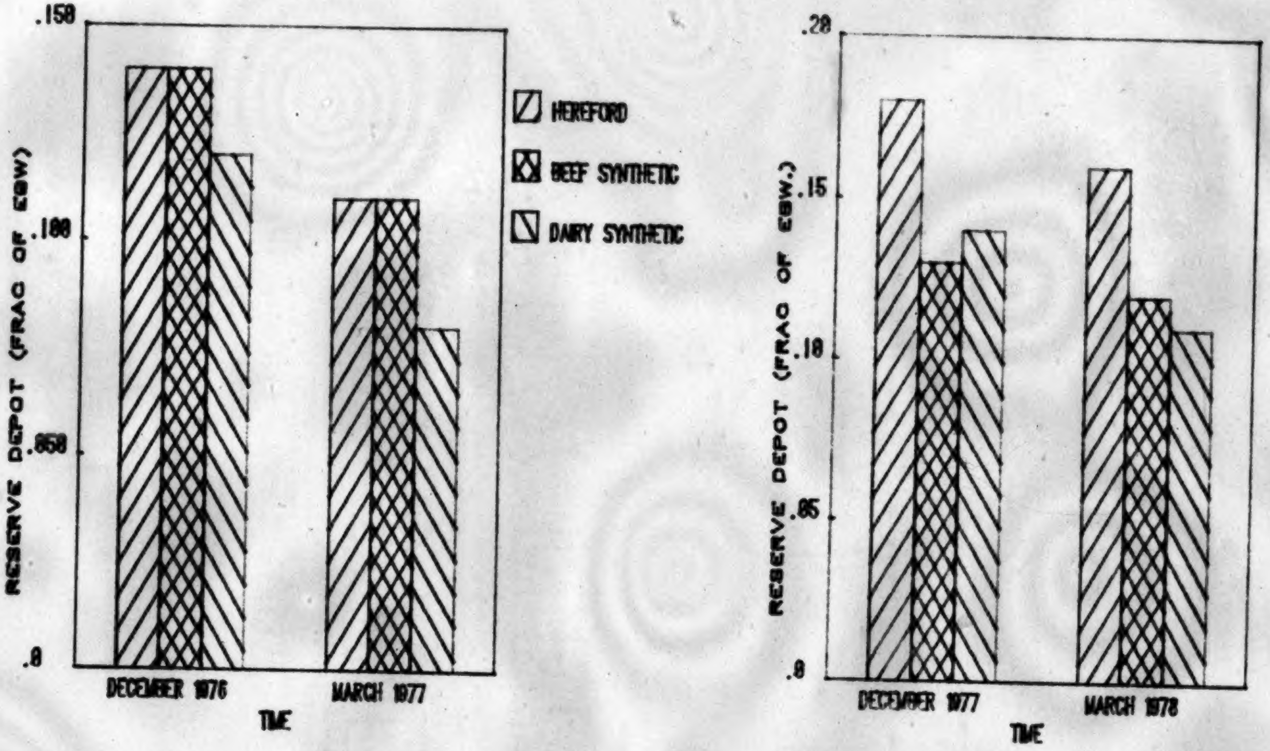

Figure 3.21 Simulated body reserve depot in cows from three lines

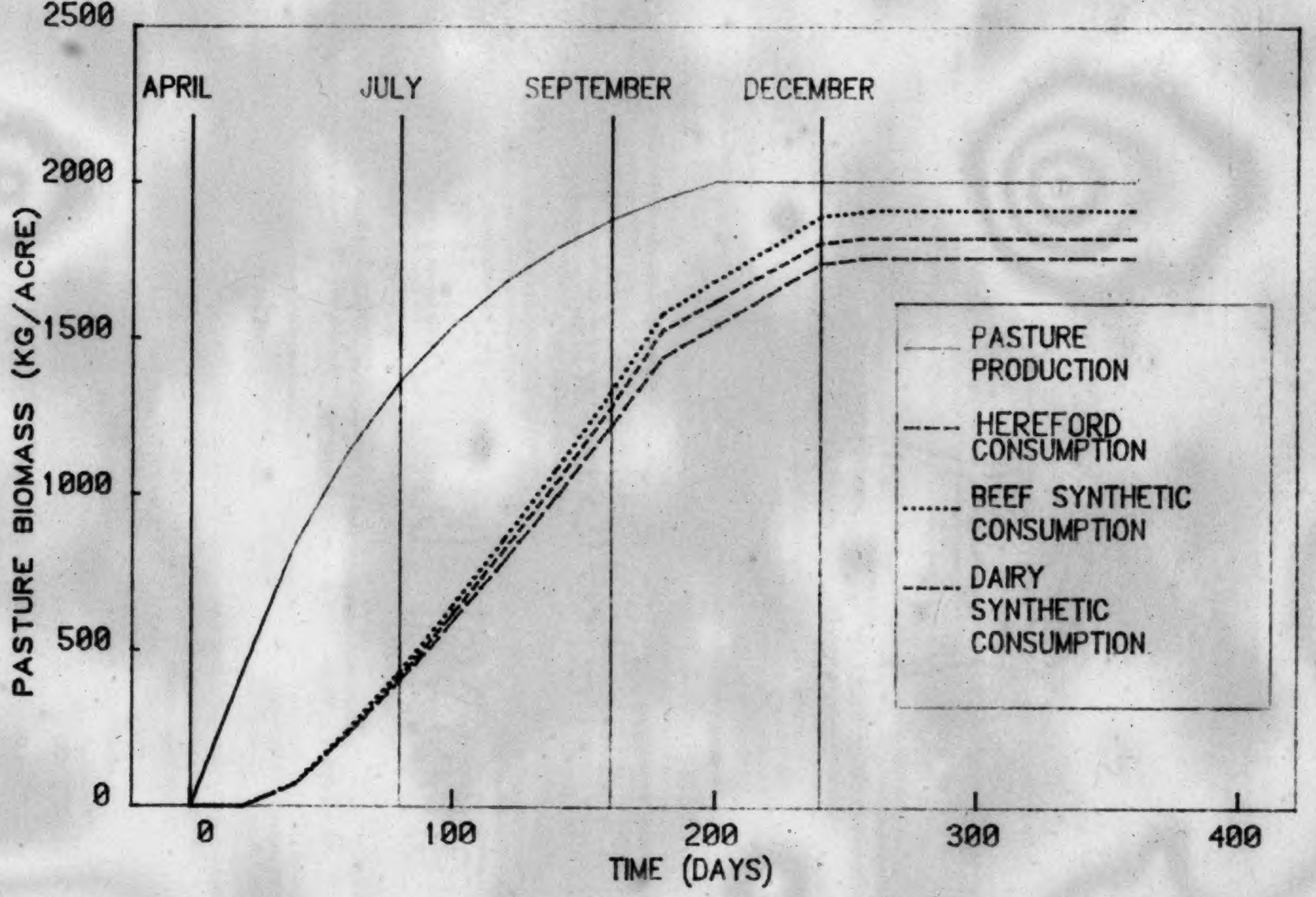

Figure 3.22 Simulated pasture biomass production and removal by cows from three lines

3.5 CONCLUSIONS

A model was developed to allow the simulation of beef production under Alberta conditions. The model was validated with exsiting observational data from The University Ranch and found to fit quite well. Therefore, use of the model in the investigation of the behavior and the biological efficiency of different management schemes, environment conditions and breeding groups within a given set of production resources is considered to be justified. If a simulation model is to lead to a greater understanding of beef production, it is obviously necessary to understand why one system is simulated to yield better results than another. For the model presented in this study, it was very convenient to produce a considerable amount of information that is simulated for a given production system. The availability of this information, coupled with an understanding of how the model works, allows an in-depth study of why two simulated systems are different from each other.

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4. EVALUATION OF ENVIRONMENTAL FACTORS INFLUENCING COW REPRODUCTION AND PRODUCTION LEVEL IN ALBERTA

4.1 ABSTRACT

A deterministic computer simulation model was used to study the effect of environmental factors on body weight and composition, feed intake, digestibility, energy balance, level of production and reproduction of range cows in Alberta.

Four management options (treatments) were evaluated: 1. improved winter supplementary feeding of 25% crude fiber, 2. controlled temperature of 20°C year round, 3. constant feeding program of 28% crude fiber under confinement conditions year round and 4. the same as 3 but with 26% crude fiber. These were compared with a control which was simulated as the actual situation at The University of Alberta Research Ranch at Kinsella.

No differences among treatments were found in the simulated 180 day calf weights, while calving interval was predicted to be shorter than the control by 16 days in all treatments, except for the third treatment where cows failed to conceive.

The causes of changes in cow weight were investigated also. Temperatures were predicted to be important factors in maintaining empty body weight during winter, whereas supplementation was predicted to be a good substitute for

controlled temperature only if provided at adequate levels of energy. Crude fiber of herbage was predicted to influence live weight mainly at the time of intensive herbage lignification (September-November), whereas fetal size was predicted to have an influence only in the last three months of pregnancy.

The effect of the treatments on dry matter intake, digestibility, energy balance and reserve depot was investigated also. Temperature was predicted to be more important in its effect on estimated dry matter intake than on digestibility, whereas feed quality was predicted to have greater influence on digestibility. Energy balance and reserve depot were estimated to be influenced by temperatures and feeding quality to the same degree.

4.2 INTRODUCTION

Reproductive and productive potentials of cattle are influenced by environmental, digestive and metabolic factors of which energy content and concentration of the diet, and the ambient temperature are probably the most important (Chapter 3). A complete quantitative investigation of the effect of these factors should thus involve a series of experiments, in each, one of the factors would be set constant, whereas the rest would vary as expected in a real situation.

There is a lack of information to indicate where, in the body of mature cows, weight change occurs (under specific environmental conditions such as those of The University Ranch), or the relationship of such changes with production and reproduction of mature beef cows. Energy requirements of beef cows as outlined by the NRC (1976), suggest that weight lost and subsequently regained from one calving to the next will have the net effect of maintaining body weight.

Most of the changes in empty body weight are derived from changes in energy balance in the body. Energy balance can be influenced either by change in energy input or energy output. An increase in intake or in energy concentration increases energy input and improves energy balance and reserve tissue gain. A large drop in ambient temperature on the other hand, may lead to a deterioration in energy balance and to a loss in reserve tissue weight. Changes in reserve tissue weight in mature beef cows are directly connected to changes in empty body weight and consequently live weight and reproduction (Chapter 3; Wiltbank and Cook, 1958; Dunn *et al.*, 1969).

Change in live weight is not necessarily a result of change in empty body weight, but can be derived from changes in gut fill and fetal size. Gut fill can vary widely according to the animal weight, maturity and physiological state, and the physical and chemical characteristics of the diet (ARC, 1980), whereas fetal weight increases as pregnancy progresses (Chapter 3).

Analysis of the interaction of factors which influence cow weight and consequently reproduction, offers a challenge for simulation modelling.

Hence the objectives of this study were:

1. to determine the effect of energy intake, diet composition and ambient temperature on the change in the seasonal weight dynamics of beef cows, and
2. to investigate the relationships between environmental conditions, and consumption, production and reproduction of cows.

4.3 MATERIALS AND METHODS

4.3.1 The Model

The Beef Cow Production Model (**COW.82**) and the Fertility Routine (**FER.82**) (Chapter 3) were used to simulate cow performance and reproduction. The model simulates growth, feed intake, milk production and reproduction as a function of genetic potential of an average mature beef cow, environmental conditions, feed quality and feed availability. Model equations represent a general relationship among the variables and do not directly consider breed effect.

Energy requirements are expressed in Mcal **ME**. The nutritional environment is defined by crude fiber concentration in the available feed, whereas demand for protein, vitamins and minerals is assumed to be met.

The model is programmed to complete at least two full annual cycles. In the first, initial conditions are set on the basis of literature estimates, so that only in the second cycle are initial conditions set by the model.

Environmental conditions are set to those prevailing at the University Ranch in the years 1976-77.

4.3.2 Management and Climate

Cows are bred mainly in July-August and calve in April-May. the cows are on the range year round and depend on natural grazing except for four months in the winter when supplementary feed is provided. Weaning occurs 180 days after calving. The climate is cool subhumid, whereas winters are long and cold. Summers are short and warm, and rainfall is low and variable (Berg, 1975).

4.3.3 Experimental Procedures

To investigate the reasons for the pattern of change in live weight over the seasonal cycle, four simulated management options were carried out.

In the first (Treatment 1) the general input parameters were set the same as those in the general model (Chapter 3), but the **ME** value of the supplementary feed was increased using a higher ratio of grain to straw in the wintering diet. The wintering diet at The University Ranch includes about 30% grain and 70% straw (Berg, 1975). A ration such as this contains about 30% crude fiber, and it is about 56% digestible for cattle under standard conditions. Increase in grain portions from 30 to 48%, would increase energy concentration in the diet, and consequently digestibility by about 9%. Thus, a wintering supplementation diet of 25% crude fiber was used to test winter feeding quality effect on change in weight pattern, production and reproduction of range cows.

In the second (Treatment 2) the ambient temperature was set at 20°C, and the simulated change in weight, production and reproduction were analyzed. In the development of the thermal adjustment factors (Chapter 3), it was necessary to assume that cows are least exposed to stressful conditions in a thermal environment of 15 to 25°C. The midpoint, 20°C, has therefore been adopted as a reference point for the various adjustments. The assumption is that beef cows of different ages and physiological status, would exhibit little or no thermal discomfort in temperatures of 20°C, so this temperature would best reflect controlled changes in conditions and productivity.

In the third and the fourth (Treatments 3 and 4), grazing was eliminated, and controlled confinement conditions were introduced, meaning a fairly homogenous diet year round. Two levels of crude fiber were tested: 28 and 26 percent in treatments 3 and 4, respectively.

The common management practice at The University Ranch, as described in chapter 3, was used to represent the control group with which the treatments were compared.

The study as a whole was designed to test whether the various patterns of change in weight, production and reproduction of beef cows could be accounted for by changes in energy intake and ambient temperature. The Hereford group was used as a representative model for the general case of range beef cows.

4.4 RESULTS AND DISCUSSION

NOTE: The results discussed in this section are those predicted by the model. The detailed timing index for the graphs is illustrated in Appendix-5.1.

4.4.1 Calving and Weaning

Simulated results of calving and weaning are presented in Table 4.1. Calf growth was not affected meaningfully at any stage by Treatment 1. Drenman and Bath (1976) and Reardon *et al.* (1978) reported little or no effect of precalving nutrition of the dam on calf birth weight and subsequent growth rate. Nicol (1979) reported a small difference of about one kg in weaning weight between the calves of precalving conditioned cows and those of non-conditioned cows. In this study the simulated control cows weaned calves weighing 170.4 kg at 180 days compared to

Table 4.1 Simulated calving and weaning results of beef cows under four management options (treatments).

Treatment	Calving					Weaning		
	Distribution %			Rate %	Interval days	Weight Kg	A.D.G Kg/day	Rate %
	30*	60*	90*					
Control	51.2	81.8	85.1	85.1	367	170.4	0.756	79.0
25% CF - (1) in supplementation	58.5	92.1	95.0	95.0	351	171.3	0.760	88.0
20 Degrees (2) Ambient temperature	58.9	92.1	95.0	95.0	351	171.6	0.762	90.0
28% CF (3) Confinment	0.0	0.0	0.0	0.0	760	0.0	0.0	0.0
26% CF (4) Confinment	58.9	92.1	95.0	95.0	351	171.6	0.762	88.0

* days from first calving.

171.3 kg of cows under Treatment 1 (which corresponded to the precalving conditioning in the reference studies).

The interval from calving to conception was expected to be significantly affected by the precalving conditioning. Calving interval of 351 days in the precalving conditioned cows (Treatment 1) compared to 367 days in the control group were simulated. This suggests that a difference of 16 days in time taken from calving to conception might be expected between the control and the Treatments 1 and 2. Wiltbank, *et al.* (1962) and Reardon *et al.* (1978) also reported shorter intervals in precalving conditioned cows.

Since calving distribution and rate in the fertility routine (**FER.82**) are directly connected to the interval taken from calving to conception in the production model (**COW.82**), calving distribution was changed in accordance with the change in calving interval.

In Treatment 1 calving rate was predicted to increase by 8.4% and weaning rate by 7.6% compared to the control. Due to prolongation of calving interval, calves had more time from calving to weaning in which to gain weight, so that unadjusted weaning weight was predicted to increase by about 11.2 kg. Keeping temperatures constant year round (Treatment 2), lead to similar predicted results to that of precalving conditioning (Treatment 1).

According to the management system practiced at The University Ranch, the precalving period occurs during winter when temperatures are usually the lowest. Thus, the precalving conditioning mainly compensates for winter stress. In cases where winter stress does not exist before calving, precalving conditioning may even cause cow obesity (Arnett *et al*., 1971).

The simulated calving interval obtained for Treatment 2 tended to be similar to that obtained for Treatment 1 and Treatment 4. The only limitation on calving interval in the Treatments 1, 2 and 4 was the result of the timing of onset of the breeding season which forced the calving interval to stay at its minimal value of 351 days. Treatment 3 with 28% crude fiber year round, forced simulated digestibility to stay at 56%. Therefore, energy availability was predicted to be limited mainly during precalving and post calving periods, and cows in this treatment were not expected to conceive and produce a calf.

4.4.2 Analysis of Change in Weight

The simulated weights for the three treatments (25% crude fiber in supplementary feed, constant temperature of 20°C year round and 28% dietary crude fiber with no pasture provided year round) compared to the control (represented by the usual management as was practiced at The University Ranch), are graphically illustrated in Figure 4.1. It is clear from this that the weight of cows in Treatments 1 and 2 was predicted to be quite similar. Treatment 1 had a slight initial advantage in weight due to some supplementary feeding in the first week of April. This advantage was maintained until November, and from this stage onward Treatment 2 had the advantage. Evidently this difference in weight could be attributed to the lack of energy in the supplementary feed provided to Treatment 1 in mid-winter.

The difference in the simulated weight between Treatments 1 and 2 in 1977 (as depicted by the the second annual cycle), for the period November to April (calving) was predicted to be substantially greater than that in the previous year. This could be attributed to the difference in climatic conditions between the years 1976 and 1977.

Due to a better energy balance in the winter before calving, cows' weights at calving in both Treatments 1 and 2 were substantially greater than that of the control. The predicted body weight of cows in Treatment 3 showed a remarkable seasonal fluctuation, reaching maximum weight at the end of the winter immediately before calving, and then dropping sharply towards June where they reached their lowest level. However, because they failed to conceive in their second year, they did not lose any weight towards their third cycle. The pattern they presented was found to be fairly typical of dairy cows fed a steady diet year round (Goldman *et al.*, 1978).

The change in body weight of the control group can be considered as the expression of the basic seasonal fluctuation in weight of cows at The University Ranch. A sharp drop in weight immediately after calving due to calf expulsion and lactation stress, followed by a sharp increase in weight due to increase in pasture quality and moisture content (which contributed to cows gain in weight via reserve tissue and liquid concentration in the body) were simulated for the first period. This period extended from mid April to September. In August there was an increase in crude fiber content of the pasture, thus rate of passage of digesta was reduced. Consequently, gut fill was increased, and a sharp increase in weight was predicted. From this point onwards, the weight dropped moderately again due to catabolism of reserve tissue which resulted from a decrease in pasture intake capacity. In December, the cows reached their second lowest weight point, and due to an improvement in energy intake through supplementary feed, they maintained a more-or-less regular increase in weight throughout the winter. The last part of this increase starting in January could be attributed to the increase in fetal weight.

Figures 4.2 through 4.5 graphically illustrate the difference in weight between each treatment and the control. Generally, the area between the graphs in each Figure represents the advantage or disadvantage in simulated weight that the treatment had over the control. It is evident from these results that part of the gain or loss in weight over the year had to be derived from changes in gut fill via change in percentage of crude fiber in the diet, and fetal size. The remaining part had to be derived from the change in empty body weight.

The predicted change in empty body weight is presented in Figure 4.6. As was shown for liveweight, both treatments 1 and 2 produced similar changes in empty body weight until the last winter when treatment 2 had some advantage over 1. But in comparision to the simulated live weight pattern (Figure 4.1), the simulated empty body weight in both treatments tended to show much less fluctuation.

To demonstrate where, in the body of mature cows, weight changes occur, the relationship between live weight and empty body weight were studied. (Figures 4.7 through 4.10). The simulated live weight, empty body weight and potential weight (as calculated based on the model in Appendix-1) are presented in a way that gut fill along with fetal weight are represented by the area between the live and empty body weight curves.

It is well known that gut fill in grazing cows occupies a substantial portion of the live weight (ARC, 1980). In the control group estimates ranged from 16.3% close to parturition to 19.1% in September when it reached its maximum value. To demonstrate the relative change in the proportion of gut fill with the changes in live weight, Figure 4.7 was drawn. It is evident that towards parturition there was a tendency for estimated gut fill to decrease due to an increase in fetal volume. Immediately after calving there was an increase in simulated dry matter intake which was accompanied by an increase in rate of passage of digesta, and as a consequence gut fill was not changed much.

An increase in crude fiber of pasture a bit later reduced rate of passage, and that caused gut fill to increase moderately until August. In August, due to accelerated herbage lignification, there was a sharp increase in gut fill which was maintained throughout the beginning of the winter until the supplementation program was introduced (Figures 4.7 and 4.8). As for the potential weight, it was shown again that in a mature cow potential growth has the tendency to average out the seasonal fluctuation (Figure 4.8).

The same analysis for Treatments 1 and 2 is shown in Figure 4.9. It is evident that the prominent difference between the treatments in the period December to April was derived mainly from differences in empty body weight. While cows under Treatment 2 maintained fairly stable empty body weights during the whole period, cows under Treatment 1 lost some empty body weight during the winter. Live weight of cows in both treatments were above the expected potential weight. This suggests that cows from the same genotype under different environmental conditions do not necessarily reach the same mature weight. Similar results were represented by Fredeen *et al.* (1981).

The same analysis for treatments 3 and 4 is shown in Figure 4.10. Since the two treatments were different only in the concentration of the crude fiber in the diet, the general pattern of weight change was fairly similar, but there was a difference in the height of the graphs representing weight change. While a diet of 26% CF (Treatment 4) maintained a stable empty body weight, a diet of 28% CF (Treatment 3) was predicted to have fluctuating EBW at calving time.

4.4.3 Dry Matter Intake

Simulated daily dry matter intake for the three treatments covering a single season, with its periods of abundance and depression is shown in Figure 4.11. The general shape of the dry matter intake curve was fairly similar to that presented for the control group in Chapter 3. Immediately after calving, intake rose steadily, due to an increase in lactation requirements. In the fourth month of lactation, intake had reached its near maximum physical capacity and predominated for the rest of the lactation period. Due to a slight temperature advantage in Treatment 1 during this period, cows under this treatment were estimated to consume more pasture than those under Treatment 2. Cows under Treatment 3 reached their assumed physical maximum capacity predicted to be 27.7% gut fill fairly early in the period (Figure 4.10). After weaning, the daily dry matter consumption of the pregnant cows dropped dramatically, due to a general decrease in energy requirements and pasture quality. While cows under Treatment 2 reached the lowest level of intake in this period, consuming only 5 kg/day, cows under Treatment 1 reached a higher level consuming 5.5 kg/day and cows under Treatment 3 consumed the highest level differences in milk production were simulated for the different treatments. As **IPDYM** varied from 10.5 to 20 kg/day, the predicted daily milk yield varied from 7.1 to 10.2 kg/day, daily milk reduction due to energy deficiency from 0.108 to 0.085 and loss in daily milk production due to past effect from 0.233 to 0.259 kg/day. The pattern of simulated daily milk yield of Treatment 1 and 2 and the control group over a period of 2 years is shown in Figure 6.9. When comparing both Treatments 1 and 2 and the control, it is evident that as **IPDYM** increases, the peak point in milk production is delayed. Plum and Harris (1971) managed Holstein cows and calves under beef management conditions and reported similar results.

As **IPDYM** varied from 10.5 to 20 kg/day, predicted overall milk reduction due to energy deficiency varied from 19.5 to 15.3 kg and predicted overall milk loss due to past effect varied from 42.0 to 46.6 kg. The differences in milk reduction can be attributed to the difference in energy intake among the treatments. The higher the potential, the greater the energy intake ability (ARC, 1980). Since the additional milk yield does not always balance out the additional energy consumed by the cows, milk loss due to energy deficiency would be less probable in these cows.

The difference in loss due to past effect among the groups was predicted to be opposite to that of the direct milk reduction due to deficiency of energy. This can be attributed to the fact that there was a difference in the relative time the reduction in milk due to energy deficiency occured. While in large **IPDYM** groups, a major portion of the milk reduction was predicted to occur in the initial time immediately after calving, in low **IPDYM** groups a major portion was predicted to occur at the very end of the season, and therefore the overall loss due to past effect was simulated to be smaller.

As P varied from 0.0978 to 0.060, the predicted daily milk yield varied from 7.1 to 8.0 kg/day, milk reduction due to energy deficiency from 0.108 to 0.130 kg/day and loss of milk due to past effect from 0.233 to 0.238 kg/day. Simulated daily milk yield in Treatments 3 and 4 and the control group over a period of 2 years is shown in Figure 6.10. As illustrated, when P decreases the height of the lactation curve is increases at a proportional rate, so that the general shape of the predicted lactation curve in all three groups was of a fairly similar pattern. In all three treatments milk reduction due to energy deficiency was predicted to occur in the terminal period before weaning, so that overall milk loss due to past effect was less pronounced than that in Treatments 1 and 2.

Simulated daily milk yield of Treatment 5 in comparison to the control over a period of 2 years is shown in Figure 6.11. Despite the improvement of 33% in predicted milk yield of Treatment 5 over the control, the milk reduction of both was fairly similar. This suggests that high potential cows theoretically have better ability to utilize the available feed than lower potential cows. The difference in milk loss due to past effect could be attributed to the difference in the relative time of milk reduction due to energy deficiency as explained in detail for Treatments 1 and 2.

6.4.5 Energy Balance

Energy balance in the cow reflects her ability to gather energy sources to cover energy demand. Increase in energy demand usually increases the cows ability to consume energy (Forbes, 1977). The question is whether or not this increase in energy intake is capable of balancing the demand.

Simulated daily energy balance of cows in Treatments 1 and 2 and the control over two years is shown in Figure 6.12. When comparing intake pattern with energy balance pattern, it is evident that differences in daily intake represent the main differences in energy balance. Additional energy which was induced by milk secretion in all cases was predicted to improve energy balance, so that during lactation time Treatment 2 was predicted to have an energy advantage over that of 1, and the latter had an advantage over the control. A fattening process which was predicted in the high potential cows later in the season, forced them to reduce intake, and that is why energy balance in Treatment 1 deteriorated towards the end of the lactation. The low energy availability estimated in the period September-December was responsible for a substantial drop in energy balance in that period.

Simulated daily energy balance of cows in Treatments 3 and 4 and the control over two years is shown in Figure 6.13. Results indicated only small differences among treatments. However, differences in energy requirements which were not compensated by additional energy intake, caused the higher potential cows to have less favorable energy balance.

Simulated daily energy balance in cows of Treatment 5 and the control over two years is shown in Figure 6.14. Analysis of the first lactation period (0 to 180 days) reveals that while the superiority in initial lactation of the treatment over the control was large, this difference was predicted to shrink towards weaning time despite the differences in intake (Figure 6.8). This could be explained by the massive increase in energy demand during the last part of the lactation, which could not be compensated for by the energy intake of the treatment.

6.4.6 Body Reserve Depot

Simulated reserve depot as a fraction of empty body weight in each treament and the control over 2 years is shown in Figures 6.15, 6.16 and 6.17. The predicted increase in body reserve tissue was found to be associated with the advantage cows had in consuming energy. This phenomenon was discussed in some detail in the preceeding section.

Substantial differences in size of reserve depot from day 180 to 320 were attributed to the artificial lack of energy imposed by the assumptions of the model (as explained before). The predicted stability in the size of the reserve depot which took place in Treatments 1, 2 and 5 from day 250 to 400 may be due to a compensatory effect (a decrease in catabolism of reserve tissue while reserves are depleted) after the earlier loss in reserves due to pasture depletion.

Differences in the general shape of the curve between the first and the second year (Figure 6.16) were due to the differences in the timing of the onset of pregnancy between the years, as well as the upper limit of reserve imposed by the model which caused cows in Treatment 3 and the control to limit their daily feed intake while reaching 20% reserve depot.

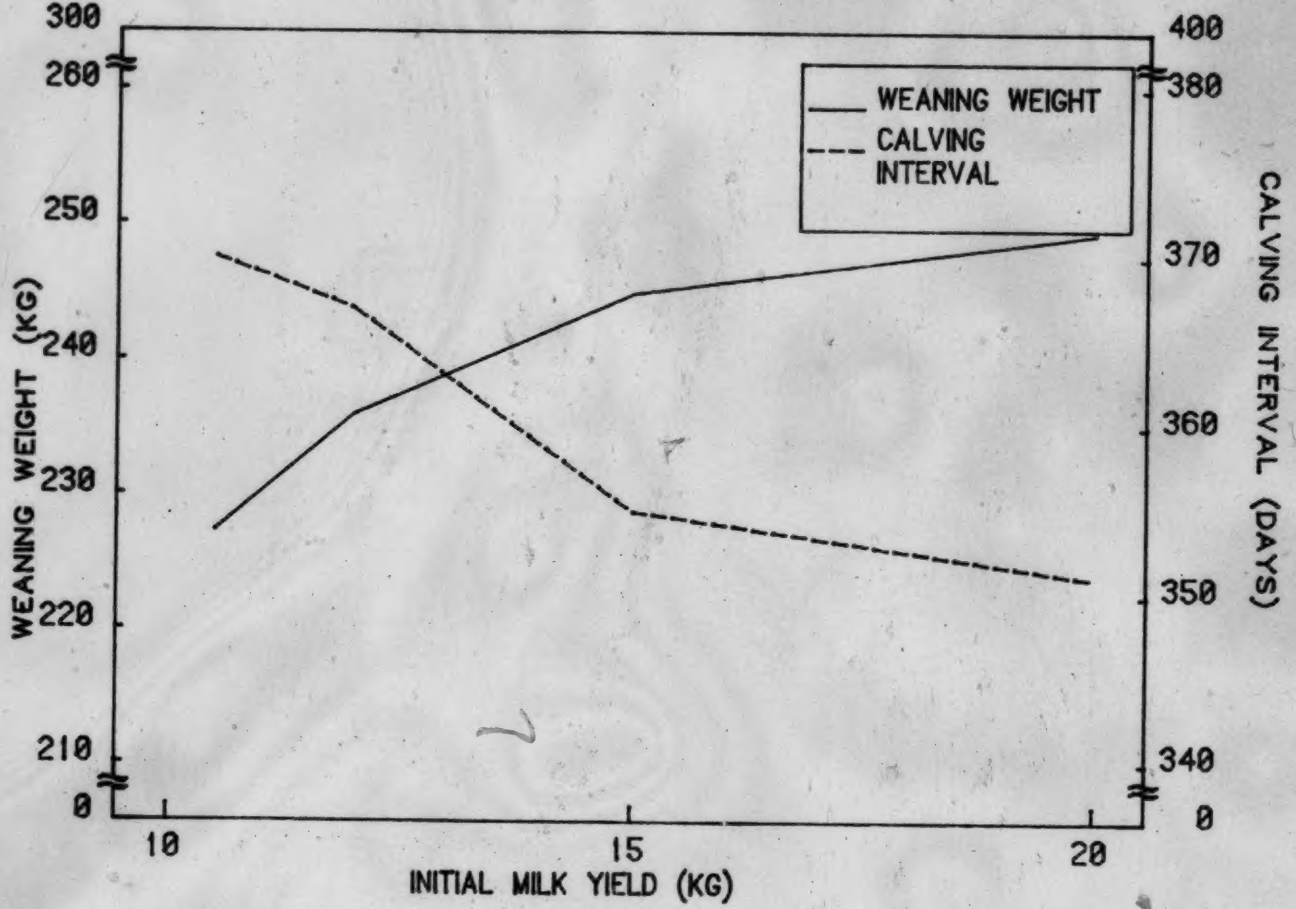

Figure 6.1 Effect of level of initial milk potential on simulated weaning weight and calving interval

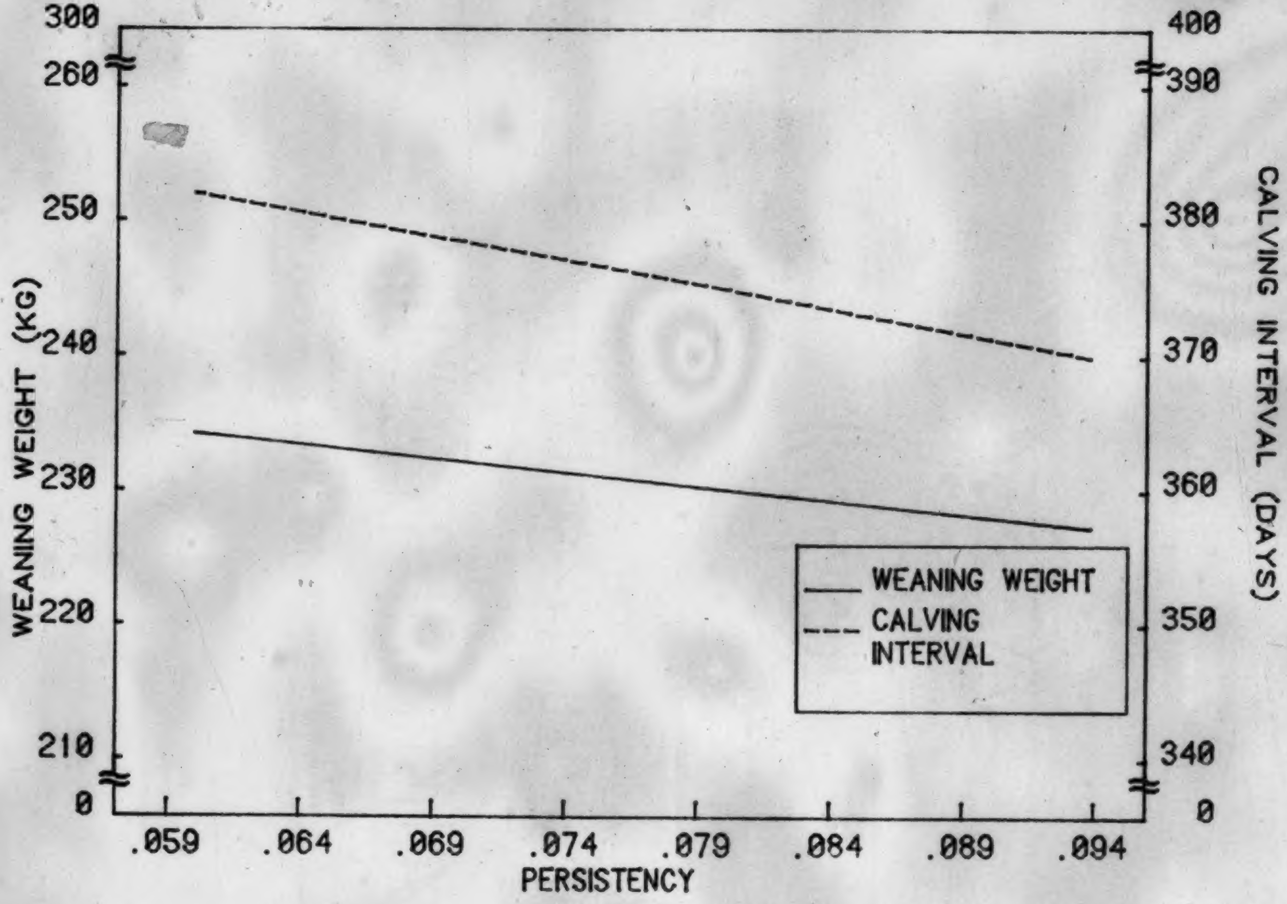

Figure 6.2 Effect of level of lactation persistency on simulated weaning weight and calving interval

6.5 kg/day.

Due to the design of the simulated experiment, the effect of nutritive value and temperature on intake can be expressed by the area between the treatments as shown in Figure 4.11 by the areas A, B, C and D. The difference between treatments 2 and 3 in the period April to December are assumed to be attributed to the effect of feed quality (represented by the shaded area A in Figure 4.11). Differences between treatment 1 and 2 are assumed to be attributed to the effect of temperature (represented by the Area B in Figure 4.11). In the period December to April, the difference between treatments 2 and 3 is assumed to be attributed to the effect of temperature (the shaded area D), and the difference between treatments 1 and 3 is assumed to be attributed to effect of feed quality (the area C). The difference between treatments 1 and 2 in this period (which is not indicated in the graph) is assumed to be attributed to the effect of the interaction of feed quality and temperature.

Analysis of the areas A and B in Figure 4.11 reveals that the assumed temperature effect in this period was relatively small when compared with the effect of feed quality. When analyzing the shaded area D in Figure 4.11, it seems that the assumed temperature effect in this period is much more important than feed quality effect due to an assumed upper limit on feed intake.

4.4.4 Digestibility

Except for the period December to April, simulated digestibility in treatments 1 and 2 were similar (Figure 4.12). Pasture digestibility (in both treatments 1 and 2) ranged from about 63% in May-June to about 45% in October-December. In Treatment 3, digestibility was maintained on a stable level of about 57% year round. Due to some advantage in feed energy, the predicted digestibility for cows under Treatment 1 was a bit higher than that for Treatment 2 or 3 during the first week of April.

The same concepts which were introduced to describe the effect of feed quality and temperature on dry matter intake, are applicable for digestibility. Evidently in the period April to September, the effect of temperature on digestibility was much less than the effect of temperature on dry matter intake. In December, supplemental feed was introduced, and temperature was dropping. The model predicts that the increase in digestibility in the period December to April is due mainly to the increased feed quality (Figure 4.12-C) than to the reduction in temperature (Figure 4.12-D).

4.4.5 Energy Balance

The simulated daily energy balance in cows expressed in Mcal **ME** per day, for the three treatments is presented in Figure 4.13. A negative balance which derived from the increase in energy demand was simulated immediately after calving. In mid May when energy consumption equalled energy demand, equilibrium prevailed and energy exchange was balanced. From this point onwards, increase in energy intake, accompanied by a decrease in energy demand, enabled the cow to accumulate energy in reserves. In mid September due to a decrease in pasture quality, the balance was changed (Treatment 1 and 2) negatively, and cows had to catabolize reserve to meet energy demand. In December due to an increase in feed quality, energy was predicted to be balanced positively again and cows anabolized energy into reserves.

The same concepts which were introduced to describe the effect of feed quality and temperature on the two previous items are also adaptable to energy balance. In the period April to September, the effect of temperature on energy balance, was relatively small when compared with the effect of feed quality. But for the period October to December the effect of temperature was larger. As for the period December to April, all three treatments maintained a positive energy balance, but while the effect of temperature was greater in December through February, the effect of feed quality had more influence in February through April.

4.4.6 Reserve Depot

The simulated reserve depot of cows under the three treatments as compared to the control are shown in Figure 4.14. Immediately after calving, cows tended to catabolize body reserve in order to obtain energy (Figure 4.13), and a decline in body reserve was simulated. When energy balance was improved (mid May), cows started to put on fat, and reserve depot was increased markedly.

In Treatment 3 the increase in reserve depot was delayed and much slower due to lack of energy immediately after calving which extended for more than 100 days. In contrast to the control group, where a sharp drop in reserve was simulated from September onwards, no drop in reserve was simulated for Treatments 1 and 2. This could be attributed to the controlled conditions of these treatments.

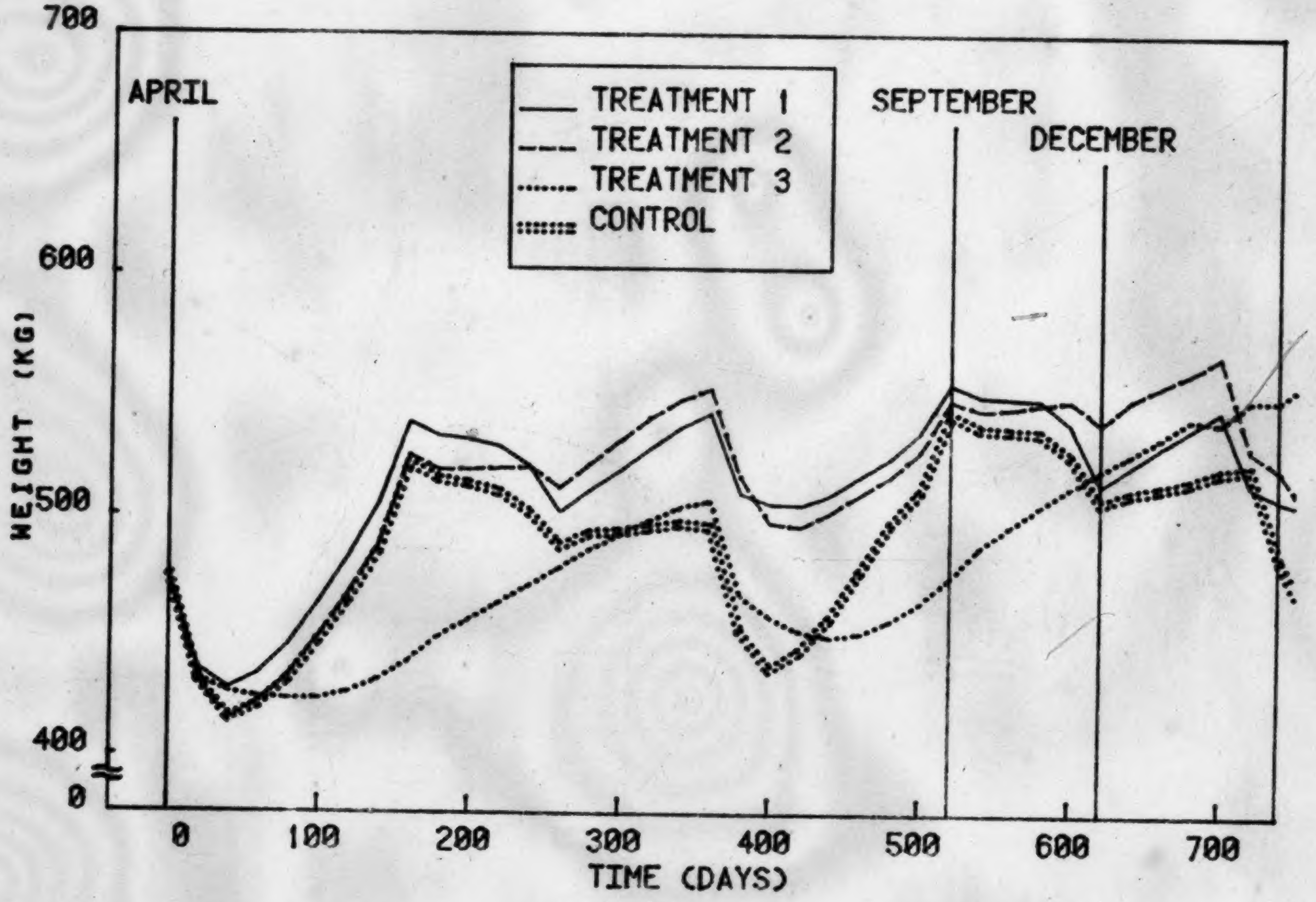

Figure 4.1 Simulated live weight dynamics of beef cows (general)

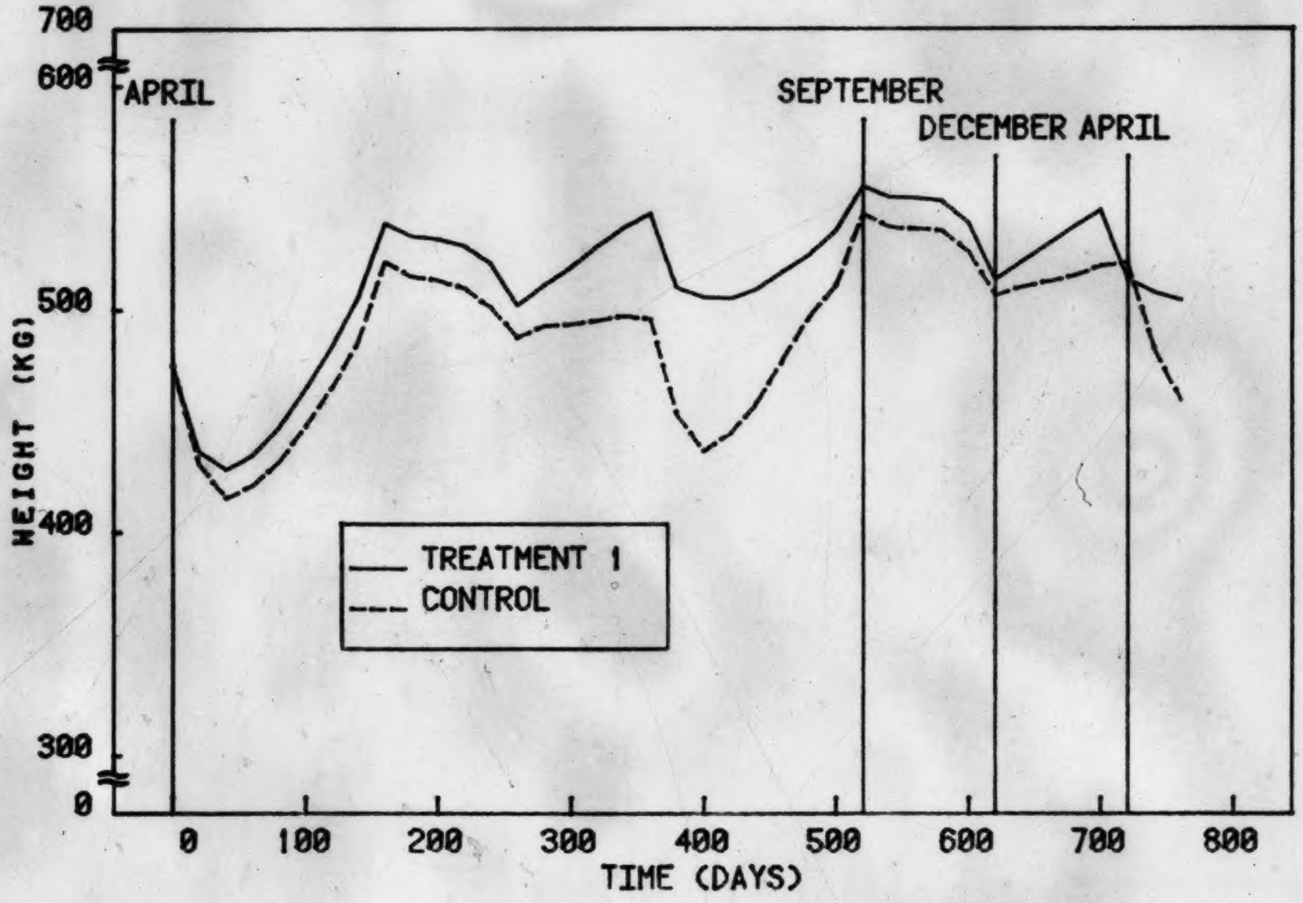

Figure 4.2 Simulated live weight dynamics of beef cows
(Treatment 1)

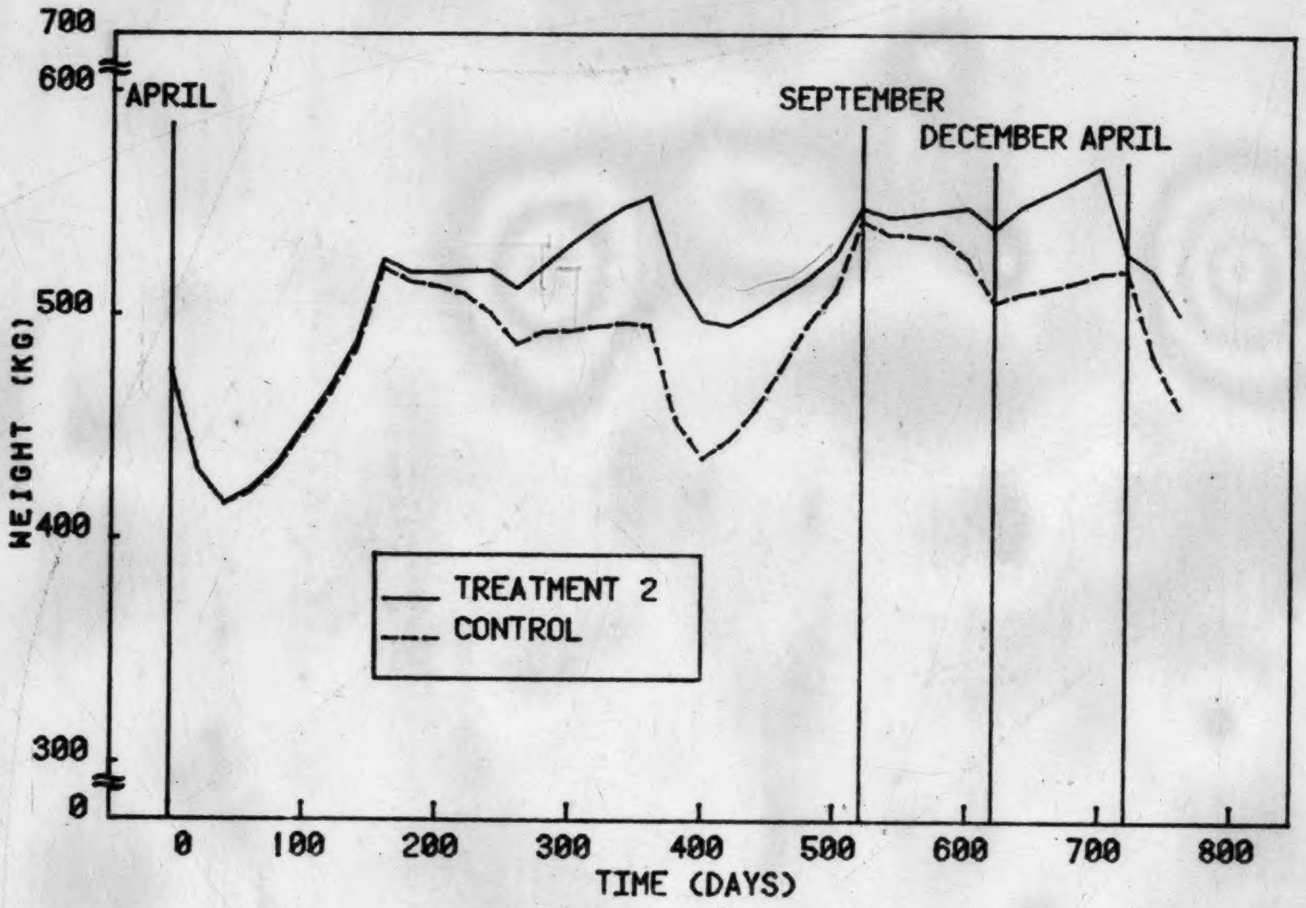

Figure 4.3 Simulated live weight dynamics of beef cows (Treatment 2)

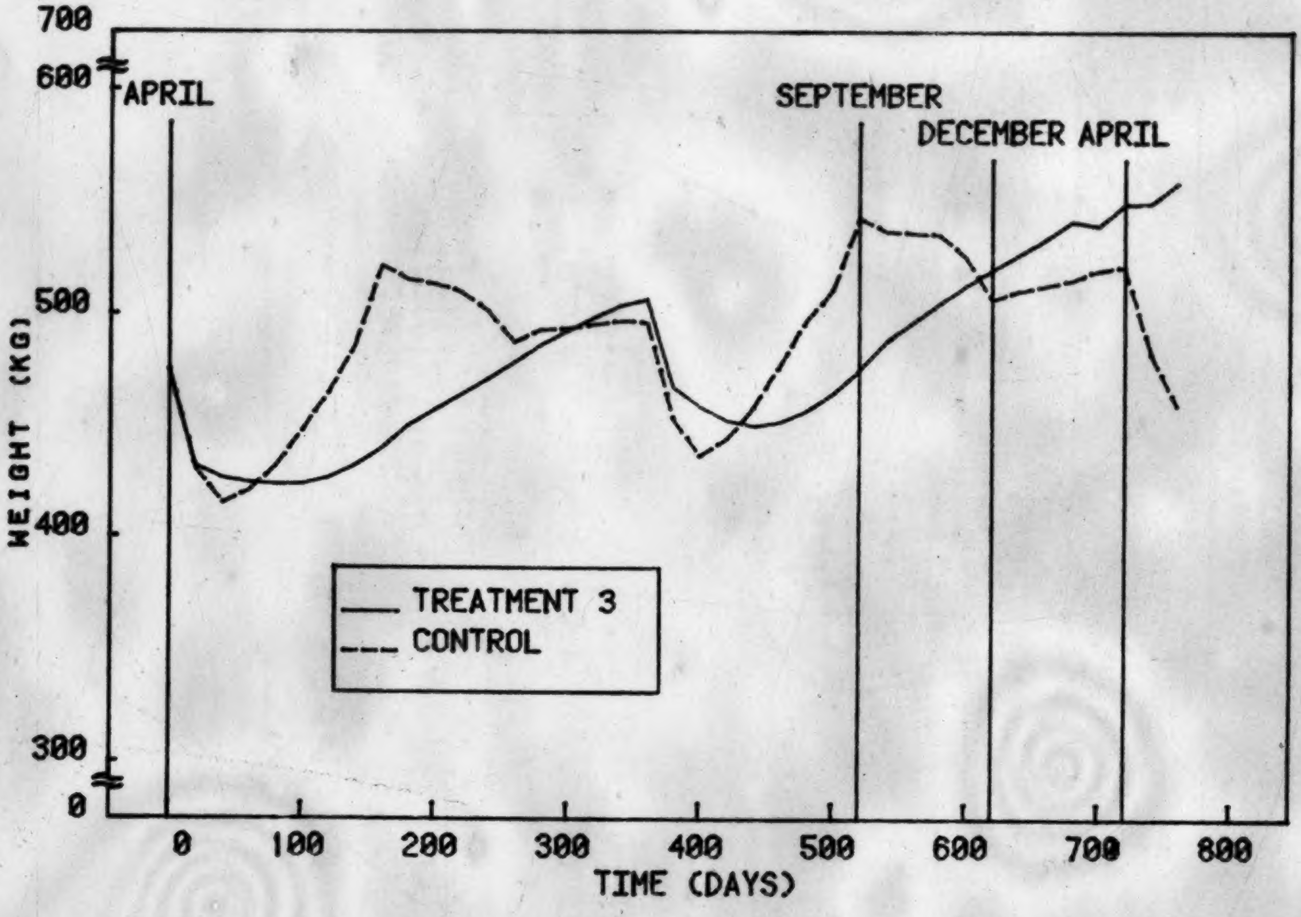

Figure 4.4 Simulated live weight dynamics of beef cows (Treatment 3)

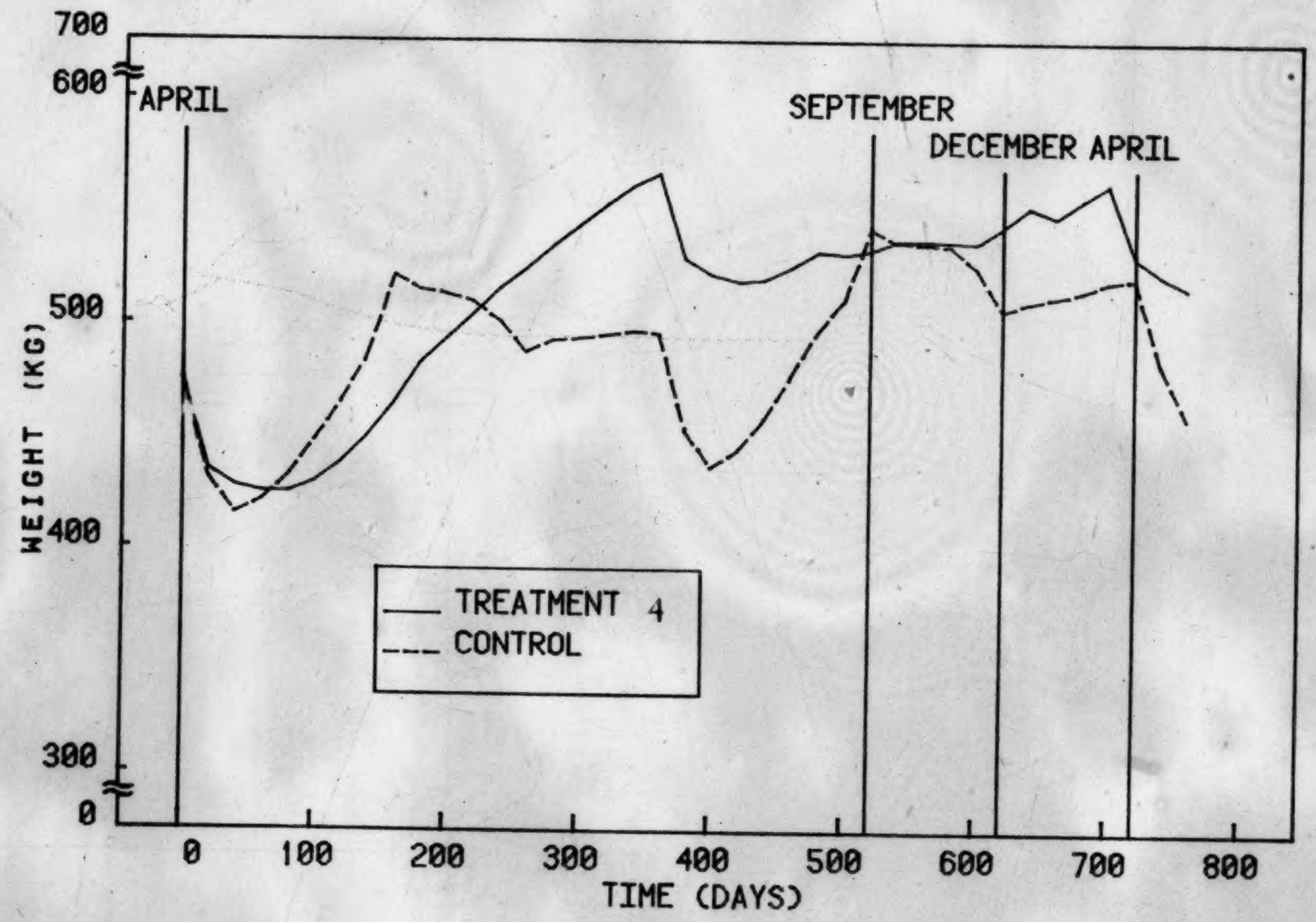

Figure 4.5 Simulated live weight dynamics of beef cows

(Treatment 4)

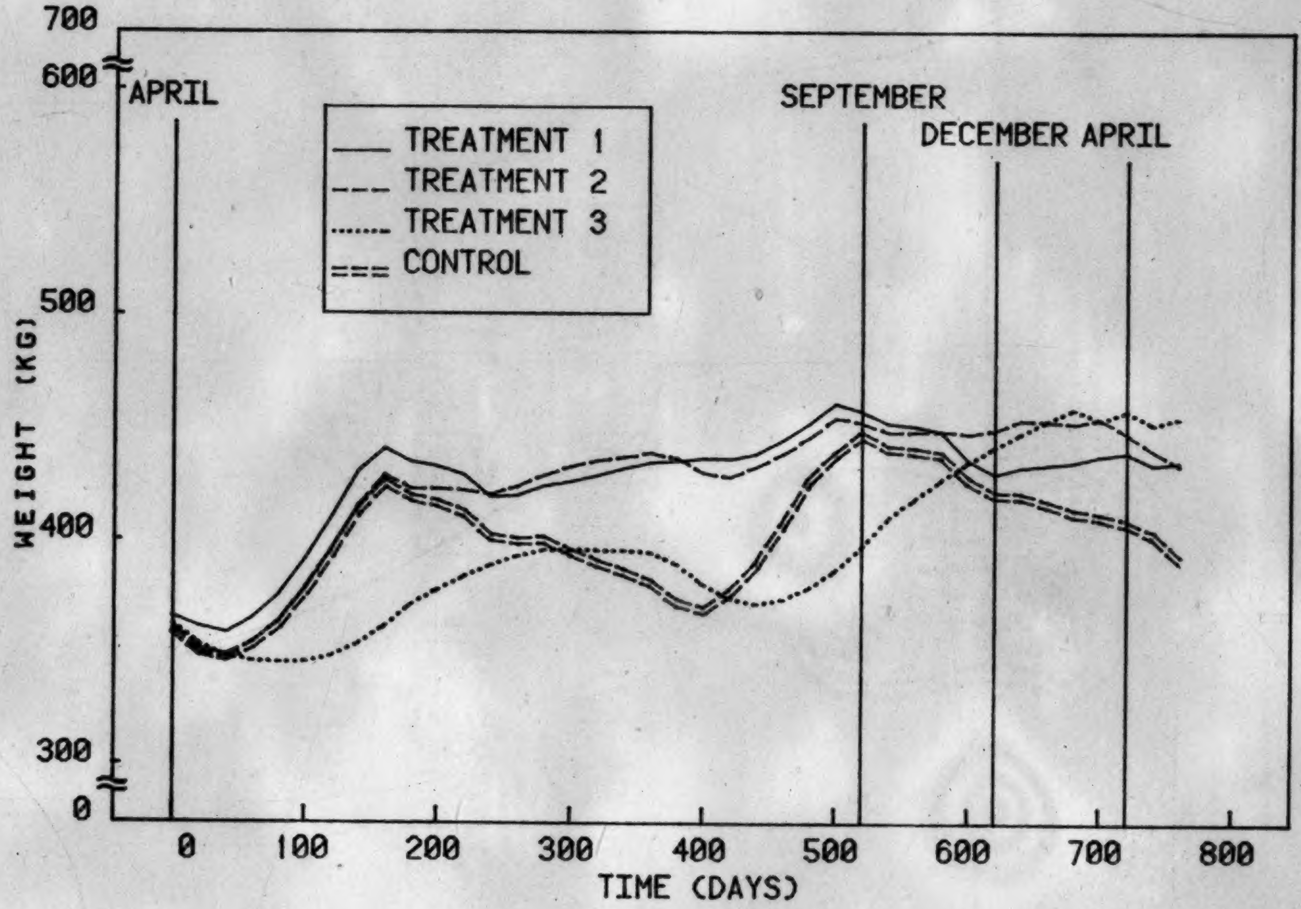

Figure 4.6 Simulated empty body weight dynamics of beef cows

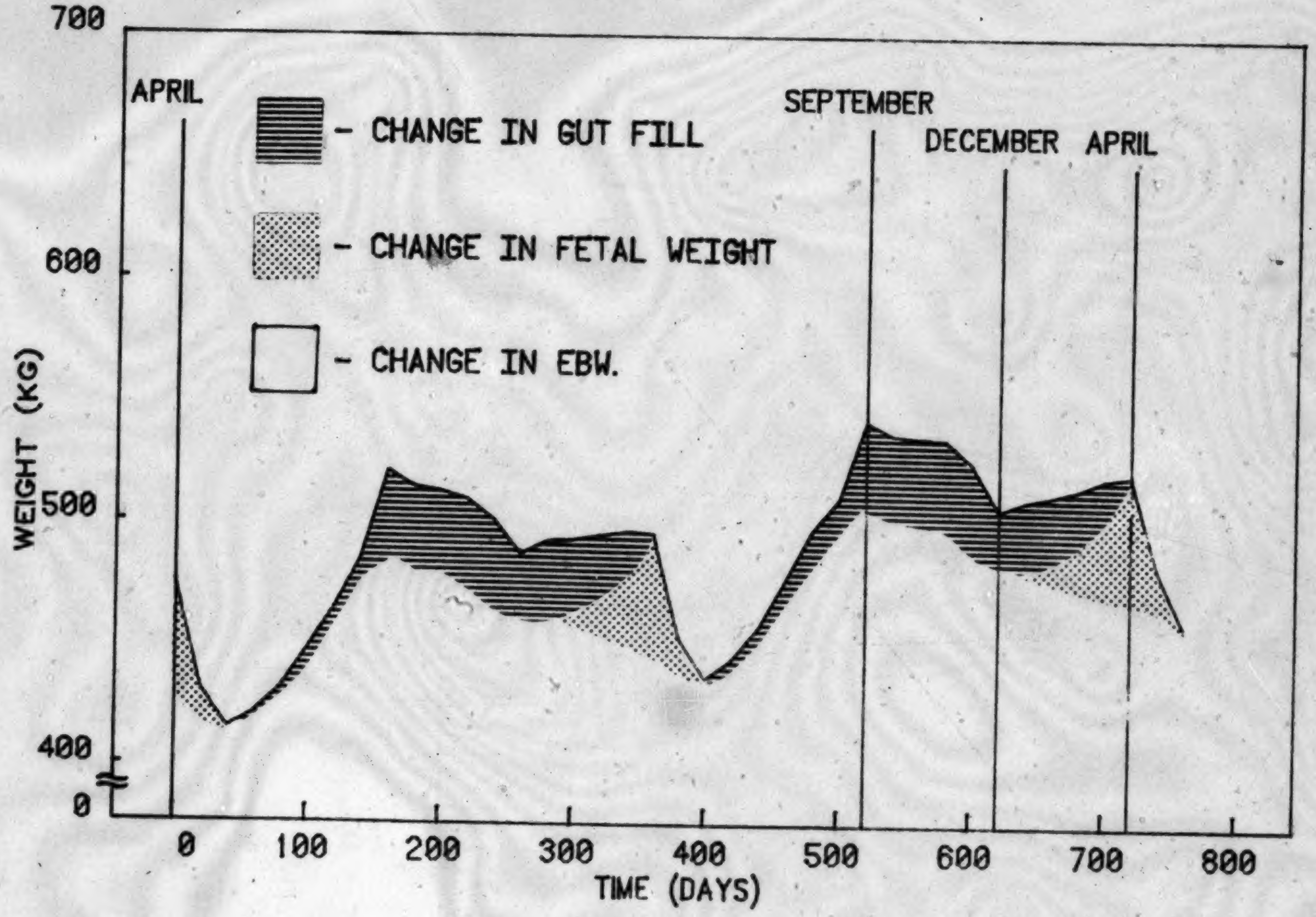

Figure 4.7 Simulated change in EBW, gut fill and fetal weight (control)

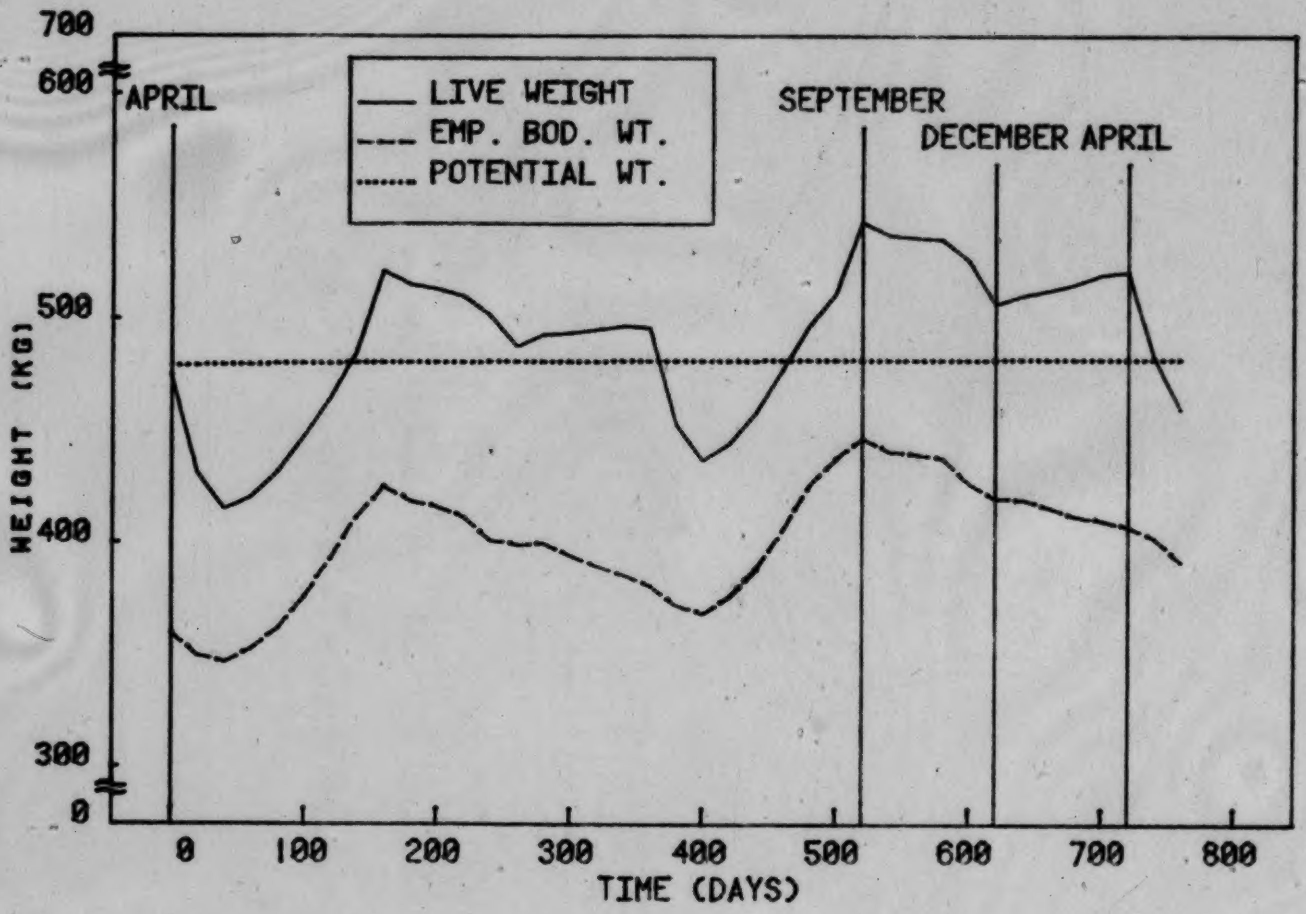

Figure 4.8 Analysis of simulated change in weight of beef cows (control)

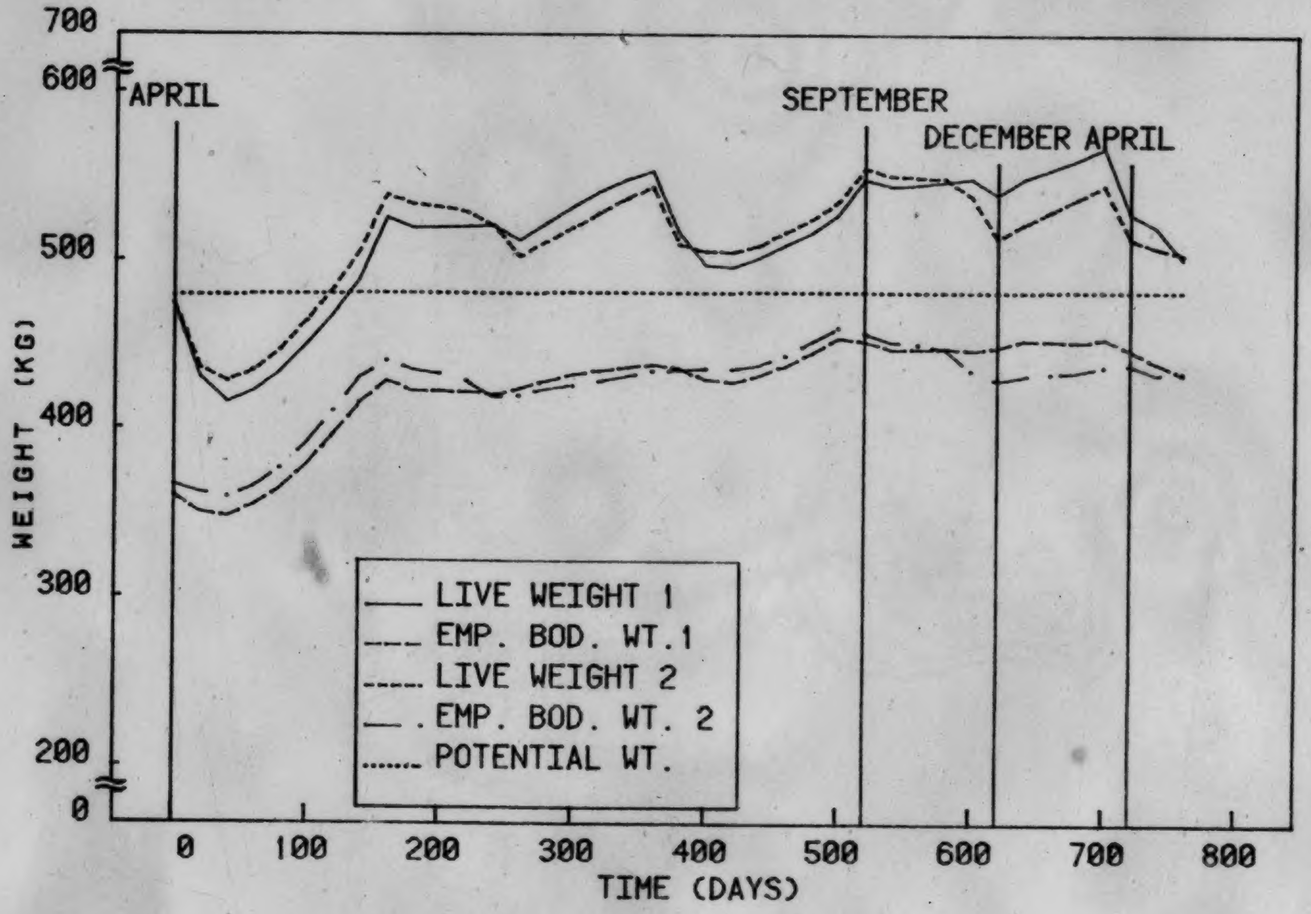

Figure 4.9 Analysis of simulated change in weight of beef cows (treatments 1 and 2)

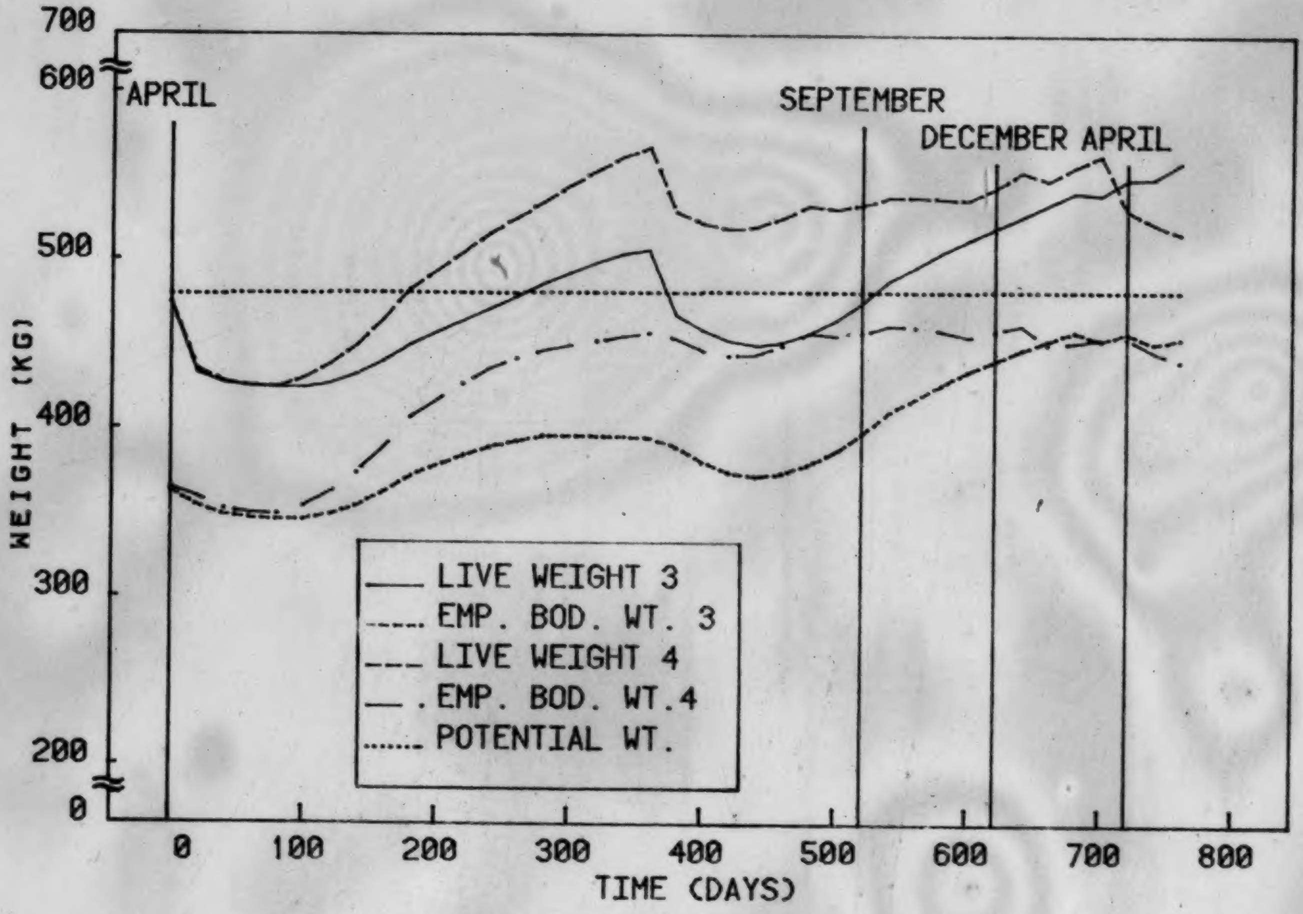

Figure 4.10 Analysis of simulated change in weight of beef cows (treatments 3 and 4)

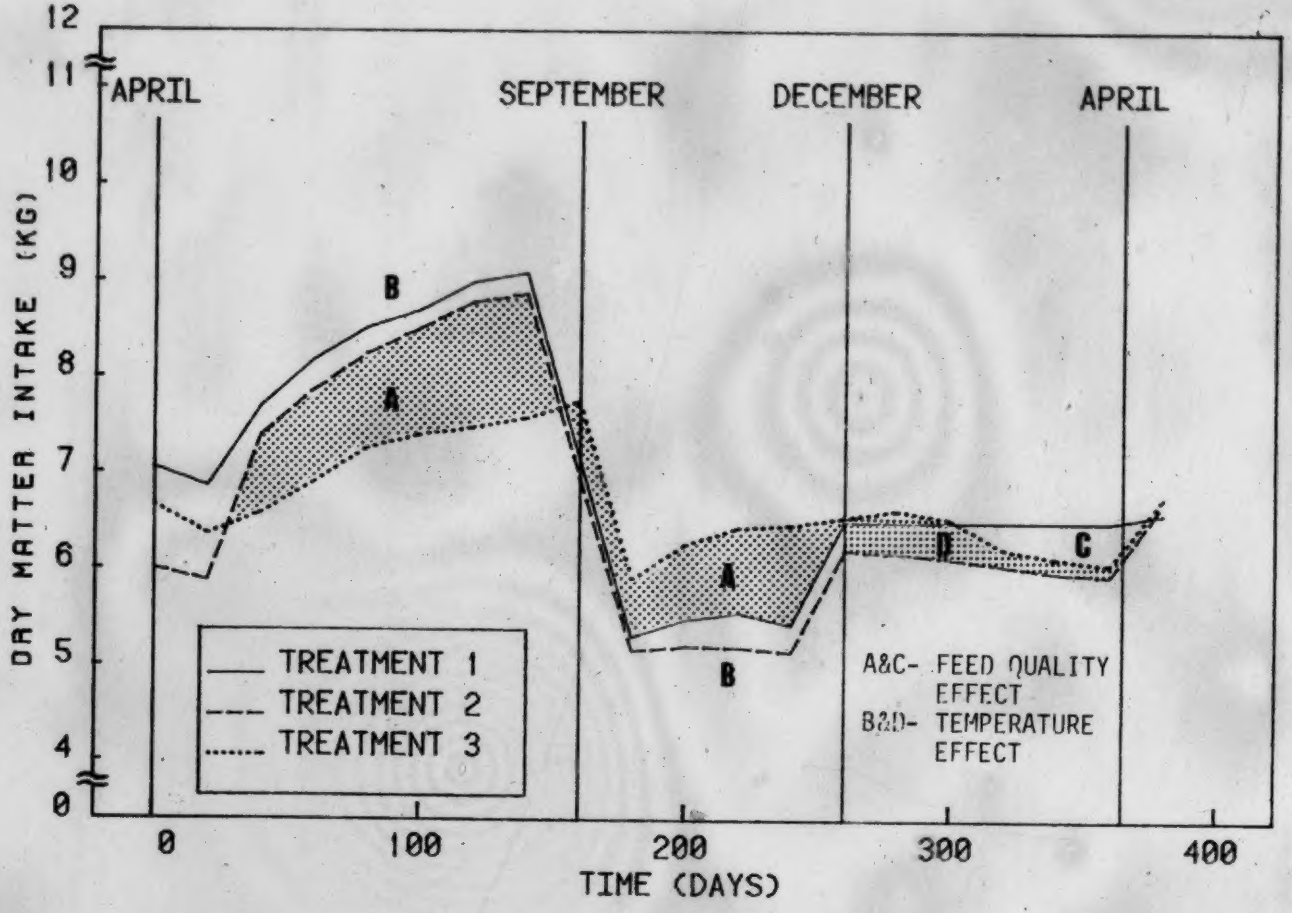

Figure 4.11 Simulated dry matter intake of beef cows

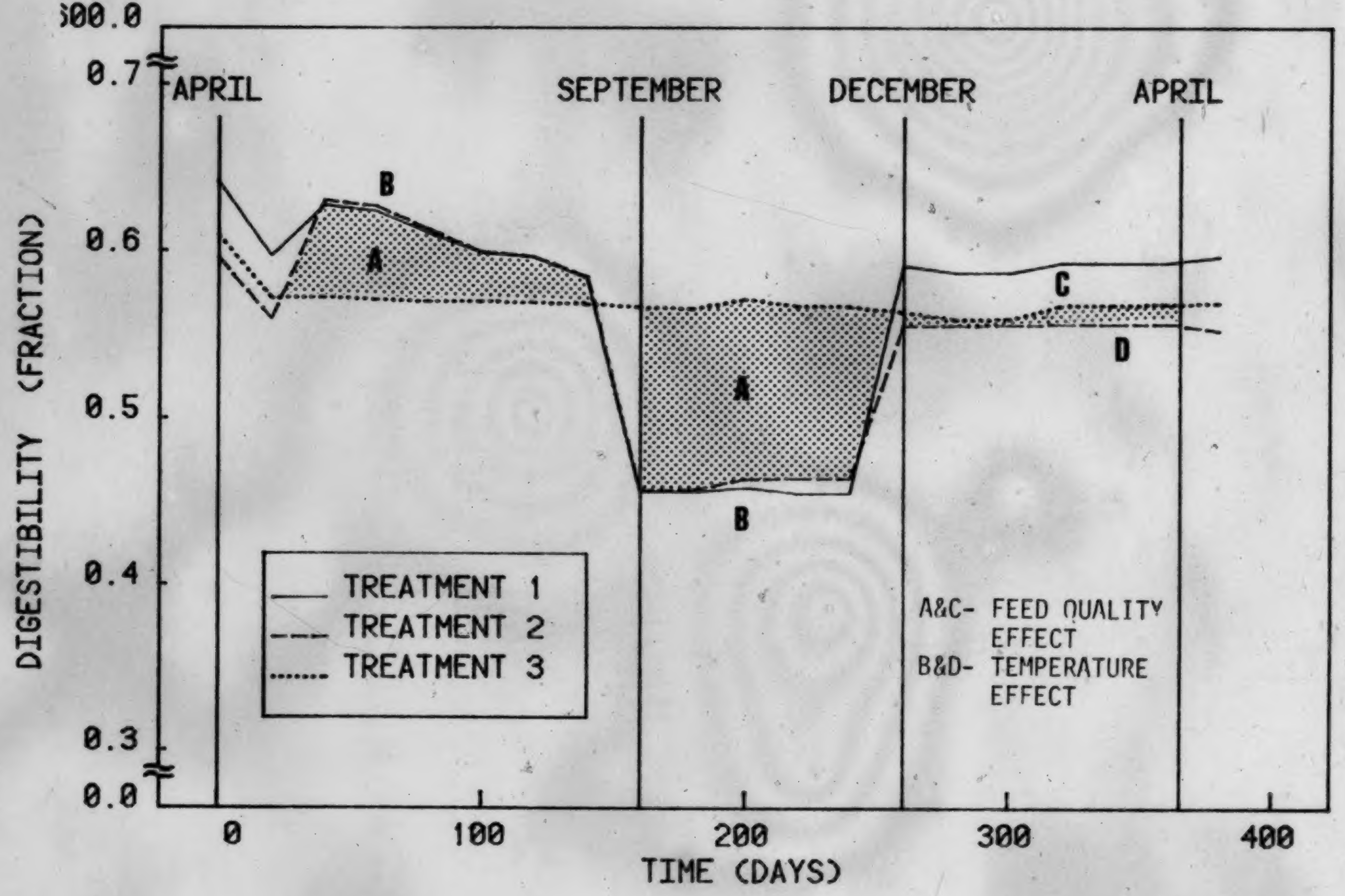

Figure 4.12 Simulated feed digestibility by beef cows

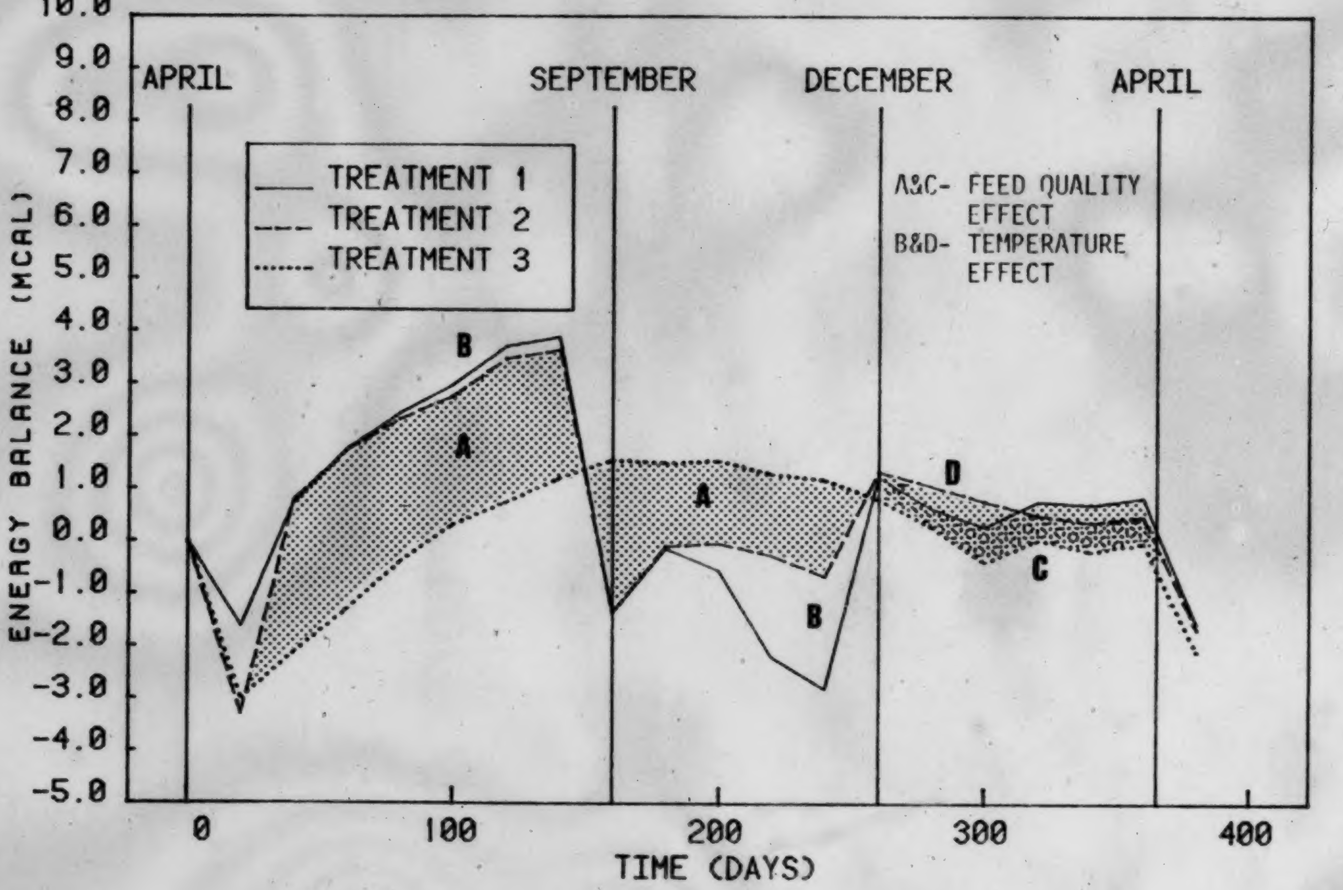

Figure 4.13 Simulated body energy balance of beef cows

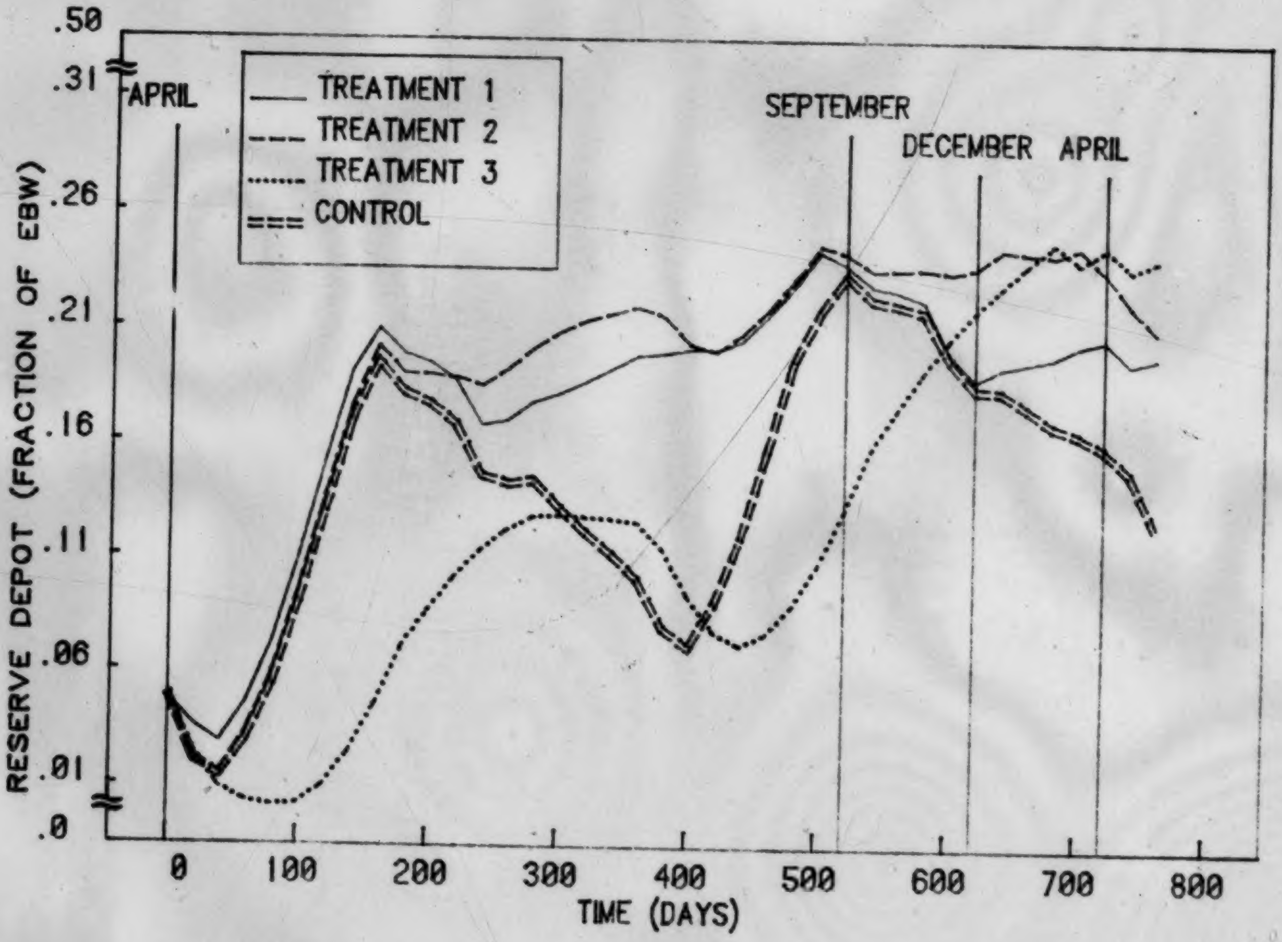

Figure 4.14 Simulated reserve depot of beef cows

4.5 CONCLUSIONS

Energy concentration of the feed is predicted to be the most influential factor in the initial period after calving, and its effect on simulated live weight is mainly via the change in empty body weight.

Crude fiber in the feed is predicted to be the most influential factor during herbage lignification at the end of the grazing season, and its effect on simulated live weight is predicted to be mainly through the increase in gut fill.

Energy concentration of the feed is again predicted to be the most influential factor in the period after maximum pasture lignification. Its effect on simulated live weight is mainly via the decrease in empty body weight.

Fetal weight is predicted to be a fairly important factor in the last phase of pregnancy (starting three months before calving), and its influence on simulated live weight is through the increase in uteral size.

Energy provided to the cows during a time of stressful climatic conditions can compensate for energy lost through heat production. In Alberta the concentration of **ME** in supplementary feed should be higher than that usually practiced at The University Ranch, in order to fully compensate for climate.

Increase in feed energy in the winter does not increase simulated 180 day weaning weight, but rather increases the time from calving to weaning by shortening simulated open days interval.

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5. A SIMULATED EFFECT OF WINTERING ON PRODUCTIVITY AND REPRODUCTION OF MATURE BEEF COWS OF DIFFERENT BIOLOGICAL TYPE IN ALBERTA

5.1 ABSTRACT

A deterministic computer simulation model was used to study the effect of a severe winter on body weight, feed intake, digestibility, energy balance, level of production and reproduction of range beef cows from three breeding groups (Hereford (**HE**), Beef Synthetic (**SY**) and Dairy Synthetic (**DY**)) under The University of Alberta Ranch management. The effect of a severe winter was compared with that of a normal winter (as represented by 1976). Only small differences in weaning weight and calving interval were predicted. This fitted corresponding data collected at The University Ranch. Some differences were found among breeding groups. The **SY** cows tended to lose more in simulated calf production under severe winter than did the other groups. Since dry matter in the winter was restricted by management constraints, no differences in dry matter consumption were simulated at any stage.

Although feed intake was not changed, digestibility was predicted to decrease due to a change in rate of passage of digesta. Energy expenses for maintenance and heat production were simulated also. **HE** cows were predicted to spend proportionately more energy on maintenance and less on heat

production, whereas DY and SY were predicted to spend more energy on heat production and proportionately less on maintenance. Thus, differences in energy balance and body reserve depot were varied accordingly.

5.2 INTRODUCTION

Wintering is the most critical and expensive time of the year in a cow-calf operation. Condition of cows in the spring is affected by their condition in the fall, the severity of the winter and management during the winter. Their condition in the fall is affected mainly by the prior grazing season (Berg, 1975).

The Alberta winter is fairly cold and often prolonged. Provision of full environment protection is neither practical nor economical for beef cattle. It is generally recognized that cattle with ample body energy reserves can withstand the stress of winter better than cattle with low reserves. It is also known that large heavy animals require a greater amount of energy for maintenance than do small animals (Webster, 1978).

Thus, in order to study wintering management methods, considerable research on the effect of cold weather on farm livestock has been undertaken at The University of Alberta Environmental Laboratory during recent years (Young, 1971).

Several studies on the influence of breed type on wintering energy requirements have been carried out at The

University of Alberta Ranch using Hereford, Beef Synthetic and Dairy Synthetic cows. (Berg *et al.*, 1976; Bolduc *et al.*, 1978). An attempt was made in those studies to determine the energetic price of a cold winter with respect to change in cow body weight and condition. Berg (1975) reported on the number of cold winter days (<-18°C) and on cow reproduction in the following year. In most of these studies severe winters were compensated by supplementary feed, so that it was difficult to evaluate the effect of severe winter on grazing cows under standard feeding conditions.

Due to the complex nature of the interaction of temperature and body condition during the grazing season, it is difficult to analyze these relationships with simple analytical methods. On the other hand, simulation models comprised of a set of dynamic deterministic differential-integral equations have been found to be an appropriate tool to use when such a problem is to be approached (Keener, 1979)

With such a model, which was described and validated in Chapter 3, harsh winter conditions can be simulated and cow weight , consumption, production and reproduction in successive years can be predicted.

Hence the objective of this study was to impose a greater degree of winter severity than an average winter by means of a simulation model, and to analyze the simulated response of mature range beef cows of different biological types.

5.3 MATERIALS AND METHODS

5.3.1 The Model

The Beef Cow Production Model (**COW.82**) and the Fertility Routine (**FER.82**) (Chapter 3) were used to simulate cow performance and reproduction. The model simulates growth, feed intake, milk production and reproduction as a function of genetic potential of an average mature beef cow, environmental conditions, feed quality and feed availability. Model equations represent a general relationship among the variables and do not directly consider breed effect.

Energy requirements are expressed in Mcal **ME**. The nutritional environment is defined by crude fiber concentration in the available feed, whereas demand for protein, vitamins and minerals is assumed to be met.

The model is programmed to complete at least two full annual cycles. In the first, initial conditions are set on the basis of literature estimates, so that only in the second cycle are initial conditions set by the model.

Environmental conditions are set to those prevailing at the University Ranch in the years 1976-77.

5.3.2 Management and Climate

Cows are bred mainly in July-August and calve in April-May. the cows are on the range year round and depend on natural grazing except for four months in the winter when supplementary feed is provided. Weaning occurs 180 days after calving. The climate is cool subhumid, whereas winters are long and cold. Summers are short and warm, and rainfall is low and variable (Berg, 1975).

5.3.3 Experimental Procedures

In this study the model was fed input parameters identical to those used in Chapter 3, except for mid-winter where the temperatures were altered to be lower than those of 1976 as illustrated in Figure 5.1.

5.4 RESULTS AND DISCUSSION

NOTE: The results discussed in this section are those predicted by the model. The detailed timing index for the graphs is illustrated in Appendix-5.1.

5.4.1 Calving and Weaning

Simulated results of calving and weaning are presented in Table 5.1. Calf growth was not affected significantly at any stage by the harsh winter preceeding the calving season. However, small differences of about 1 kg were simulated for the advantage of cows exposed to a normal winter compared with those exposed to a harsh winter. Harsh winters had more debilitating effects on **SY** cows than on **HE** or **DY** cows: 1.4, 1.0 and 0.7 kg difference in weaning weight between the two years were simulated, respectively.

Table 5.1 Simulated calving and weaning results of beef cows from three breeding groups in normal and severe winter years.

		Calving					Weaning		
Breeding Group		Distribution %			Rate %	Interval days	Weight Kg	A.D.G Kg/day	Rate %
		30*	60*	90*					
HE	Normal	51.2	81.8	85.1	85.1	367	170.4	0.756	79.0
	Severe	50.9	80.3	83.6	83.6	370	169.4	0.751	75.2
SY	Normal	54.6	86.3	89.7	89.7	358	210.0	0.961	83.4
	Severe	51.3	81.9	85.2	85.2	362	208.6	0.968	76.4
DY	Normal	50.0	78.9	82.1	82.1	370	226.3	1.027	76.3
	Severe	49.8	78.7	82.0	82.0	371	225.6	1.033	73.8

* days from first calving.

Berg (1975) in an extensive report on the Kinsella project, reported days of temperatures below -18°C and weaning weights of calves in the following year. Regression analysis of the reported data revealed that the effect of long periods of low temperatures in the winter on the weaning weight of calves in following years was significant in **SY** and not significant in **DY** and **HE** (Appendix-4 section 1 in the table) .

The interval from calving to conception was affected only slightly by the harsh winter. Calving intervals of 370, 362 and 371 days compared to 367, 358 and 370 days in **HE**, **SY** and **DY** were simulated, respectively. Similar results represented by non significant correlation coefficients were found when data from Berg (1975) was analyzed. (Appendix-4 section 2 in the table).

Since calving distribution and rate in the fertility routine (**FER.82**), are directly connected to the interval taken from calving to conception in the cow production model (**COW.82**), the calving distribution was changed in accordance with the change in calving interval between the two winter years. Beef Synthetic cows were predicted to be affected the most by the harsh winter, responding with a reduction of 4.5% in simulated calving rate, compared to 0.1 and 1.5% in **DY** and **HE**, respectively. In spite of the larger decrease in calving rate of **SY** cows after the harsh winter, they still managed to maintain the highest calving rate among the groups: 85.2 compared to 82.0 and 83.6% in **DY** and **HE**, respectively.

Due to the prolongation of the open-days interval, subsequent calves had less time for growth from calving to fall weaning, so that the predicted weaning weight was decreased by: 2.2, 5.8 and 1.03 kg in **HE**, **SY** and **DY**, respectively (a multiplication of the additional time taken to calving by the marginal daily gain).

5.4.2 Analysis of Change in Weight

The simulated weights of cows from the three breeding groups over a period of two years separated by a harsh winter is shown in Figures 5.2, 5.3 and 5.4. In all cases an increase in energy demand without increase in energy supply caused a decrease in mid-winter predicted weight. Differences in predicted rate of change of weight were larger in **SY** and **HE** than they were in **DY** cows.

5.4.3 Dry Matter Intake

Simulated total and average daily dry matter intake of the three breeding groups in the two winter years are shown in Table 5.2. No difference in dry matter consumption was noticed among groups. This could be attributed to the way in which wintering was managed and defined by the model. During the supplementary program in the winter, the maximum amount of dry matter allowed to the cows was 6.5 kg/day. Therefore, the winter effect on dry matter consumption was not allowed to be expresed.

Table 5.2 Simulated dry matter intake and energy balance of beef cows from three breeding groups in normal and severe winter years.

Breeding Group	Winter Conditions	Dry Matter Intake		Energy					
				in Feed		Demand		Balance	
		kg	kg/d	Mcal	Mcal/d	Mcal	Mcal/d	Mcal	Mcal/d
HE	Normal	2439.1	6.77	5257.6	14.4	5257.4	14.4	0.2	0.00
	Severe	2435.9	6.77	5240.2	14.3	5475.6	15.0	-235.4	-0.64
SY	Normal	2649.8	7.42	5708.1	15.6	5664.0	15.5	44.1	0.12
	Severe	2646.8	7.41	5690.6	15.6	5881.5	16.1	-190.9	-0.52
DY	Normal	2621.8	7.37	5648.5	15.5	5716.9	15.7	-68.4	-0.18
	Severe	2623.1	7.37	5639.5	15.4	5915.8	16.2	-276.3	-0.75

5.4.4 Digestibility

As defined in the model, decreased temperatures caused a decrease in digestibility by provoking increased rate of passage of digesta (Christopherson, 1976). In addition to its effect on digestibility, the harsh winter was predicted to have some influence on energy density of the consumed feed. From the data on the concentration of energy in the dry matter (Table 5.2), it was predicted that the average **ME** value of the feed in a normal winter is a bit higher than that in the harsh winter (2.154 compared to 2.150 Mcal/kg **DM**, respectively).

5.4.5 Energy Balance

Total and daily average energy requirements, energy intake and energy balance were simulated for the three breeding groups in normal and harsh winter years (Table 5.2). Energy demand in a harsh winter year was greater than that in a normal winter year by: 4.1, 3.3 and 3.5% for **HE**, **SY** and **DY** cows, respectively.

Since the energy in the feed was kept at the same level for both years, predicted energy balance in the harsh winter year was relatively less favorable. While the average concentration of the feed consumed by the cows in both years was 2.15 Mcal/kg **DM**, the average concentration of feed required was: 2.25, 2.22 and 2.25 in harsh winters compared to 2.15, 2.14 and 2.18 in the normal winter year in **HE**, **SY** and **DY** cows, respectively.

In the normal winter year, **HE** cows succeeded in totally balancing their energy budget, but in a harsh winter they had a simulated deficit of 235.4 Mcal. **SY** and **DY** cows lost 235 and 207.9 Mcal more in a harsh winter year than in a normal year (Table 5.2). This loss in energy can be considered as the main reason for loss in body weight during the winter (Young, 1971).

It is evident from the structure of the model, that an increase in energy requirements in the winter is attributed mainly to the increase in maintenance requirements (Young, 1971). Thus, it was cosidered important to analyze the effect of cold winter temperatures on maintenance and heat production of the cows. Since in a preliminary run of the model, differences in the energy pattern among groups were found to be fairly small, it was decided to use only the Hereford cows to graphically illustrate the difference between normal and harsh winter years.

The simulated daily energy demand for maintenance in normal and harsh winter years is shown in Figure 5.5. The shaded area represents the total increase in energy for maintenance in a harsh winter. While in **HE** cows maintenance was increased by 129.3 Mcal, in **SY** and **DY** it was increased only by 101.8 and 96.8 Mcal, respectively. These differences between the groups can be attributed to the effect of cow condition (**COND**) and weight as defined by the model. Since **HE** cows were usually in better condition in the winter, a drop in temperature to a very low level forced them to lose relatively more reserve than that in less conditioned cows. Thus, the change in **COND** as defined by the model was greater in **HE** than that in **SY** and **DY** cows. The model does not consider the internal insulation value of the extra fat.

Young (1971) measured change in weight and fat cover in thin and fat cows over a cold winter and found the maintenance requirements to behave in a fairly similar way to that predicted by the model. While **HE** cows required proportionally more energy for maintenance during cold weather, they still required less than the other groups due to their smaller body size, as suggested by Webster (1978).

The current simulated energy demand for heat production at temperatures below the lower critical temperature is shown in Figure 5.6. At air temperatures below the lower critical temperature, heat loss to the environment exceeds that which would be produced as an inevitable consequence of metabolism. In order to maintain homeothermy, heat loss must be matched by an increase in food energy or mobilization of tissue reserves. The thermal demand is measured by the increase in metabolic rate that it invokes.

The difference in heat production due to increases in metabolic rate is indicated by the shaded area in Figure 5.6. Generally, energy for heat production was generated only during the period from November to February. Two peaks were observed-one in the end of November and the second in the middle of February. In a normal year such as 1976, both peaks were relatively low, about 1.7 Mcal/day, whereas in

1977, which was a bit colder (Figure 5.1), the first peak reached 2.4 Mcal/day, whereas the second repeated those which prevailed in 1976. In a harsh winter such as in the simulated one, peaks were predicted to reach substantially larger values (Figure 5.6). Since heat production under the same critical temperature and feed intake is a function of body surface (Chapter 3), it is clear that heat production would be greater in **SY** cows than **DY** and **HE** as shown in Table 5.2

The simulated energy balance in the two winter years is shown in Figure 5.7. The shaded area in the figure represents the total difference in energy balance corresponding to the same values presented in Table 5.2. Robertshaw (1981) discussed the effect of environment on energy balance, and noted that change in energy balance in cows can be attributed to reduction in gross energy intake, reduction in digestibility (Kennedy *et al.*, 1977) and elevation of maintenance requirements, which would reduce the proportion of gross energy intake available for productive purposes.

5.4.6 Reserve Depot

The simulated reserve depot of beef cows in the two winter years is shown in Figure 5.8. The general shape of the reserve depot curve in the harsh winter was the same as that in the normal winter year (Chapter 3), except for the period from November to March where the decrease in reserve depot was greater in cows exposed to a cold winter.

It was demonstrated by Graham *et al.* (1959), that fat is the primary tissue substrate used during cold exposure. However, in their study they showed that degrees of fat utilization depend on the level of feeding, and that at higher levels of feed intake, the amount of fat that is oxidized is much less. It is evident that due to their total demand for energy in a harsh winter year over a normal year, **HE** and **SY** cows demanded proportionally more and therefore lost more reserve tissue, whereas **DY** cows demanded proportionally less and lost less. Young (1971) reported changes in fat cover in a group of fat and thin cows over winter and found fairly similar results.

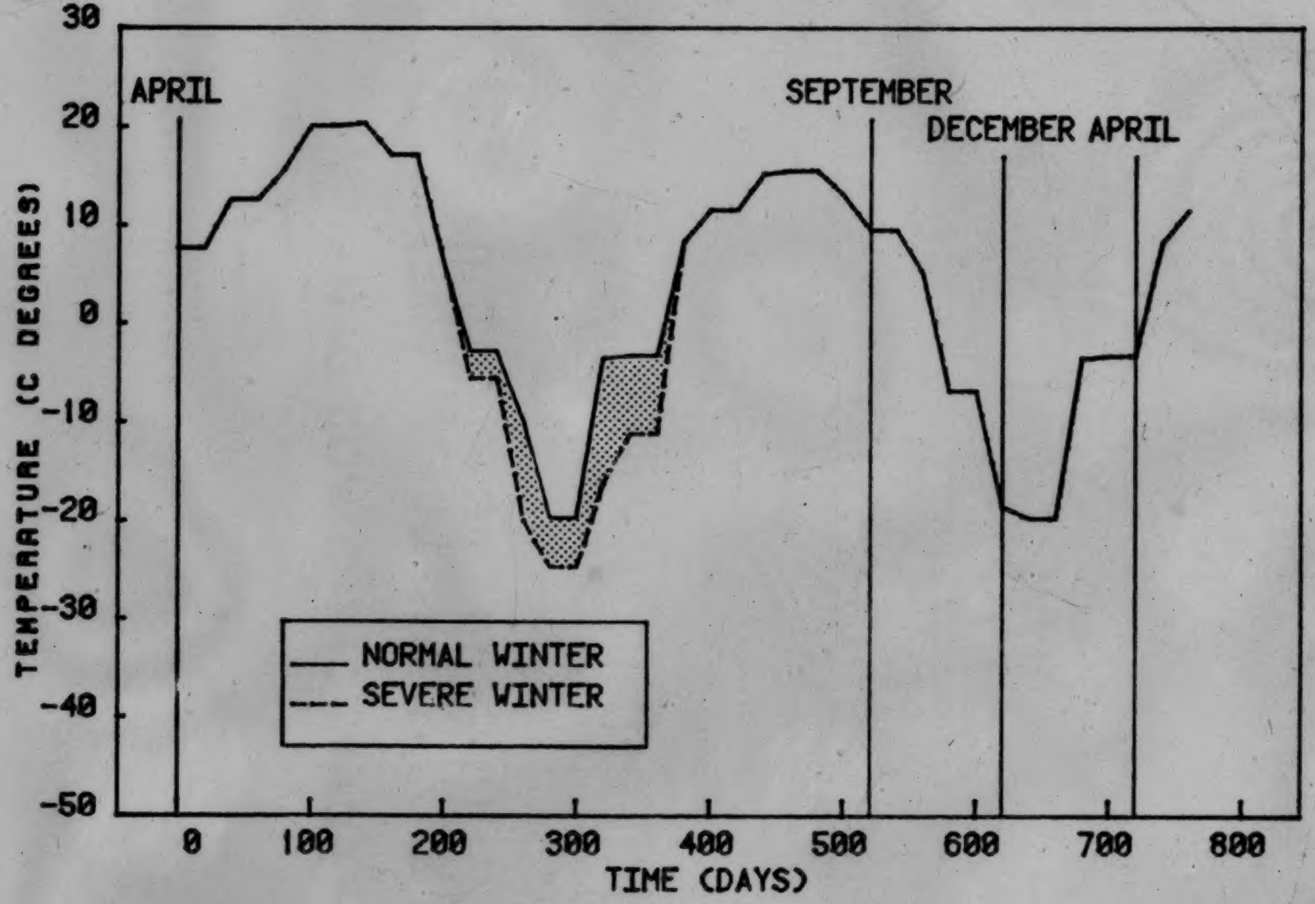

Figure 5.1 Monthly average temperatures in normal and severe winter years

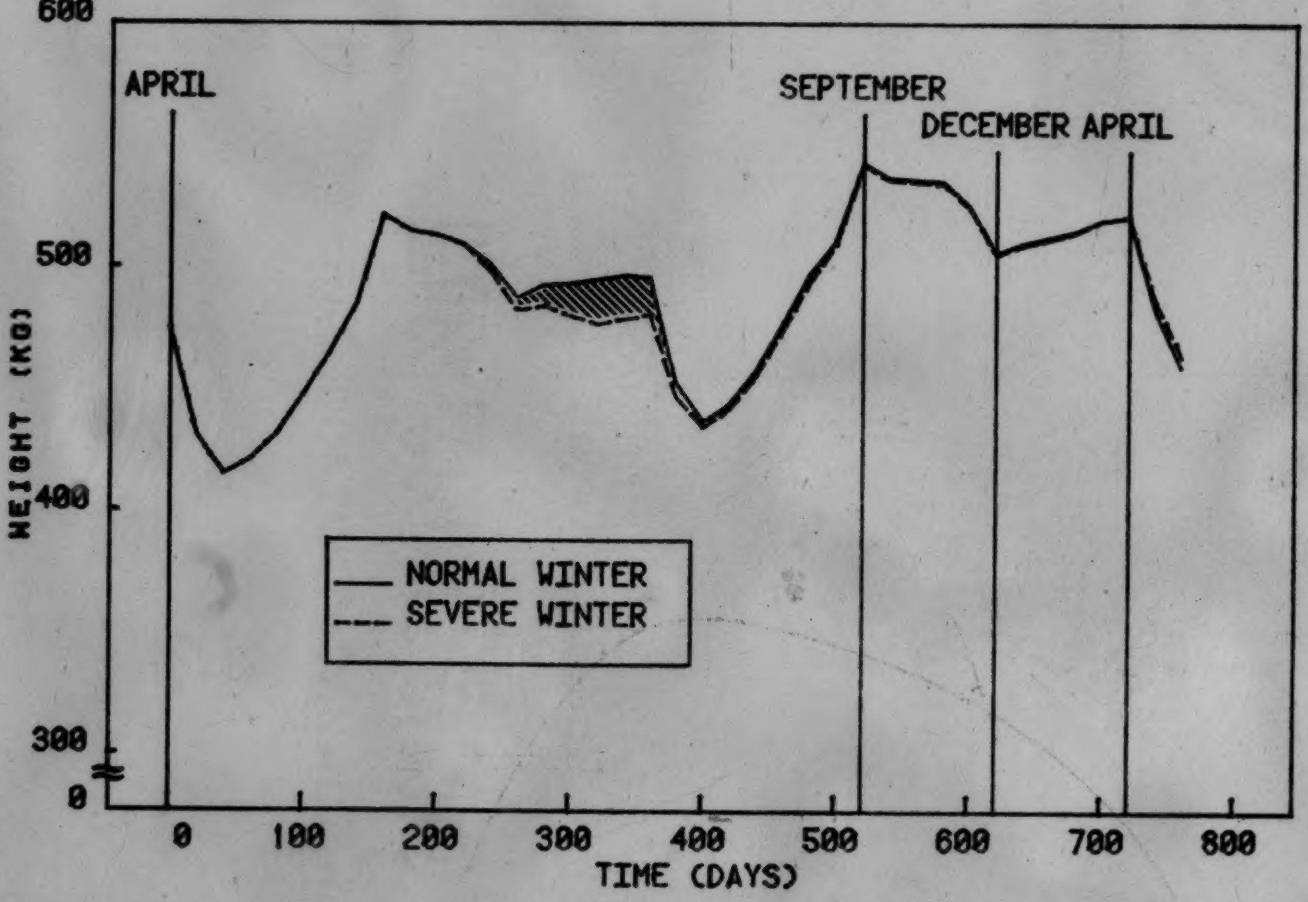

Figure 5.2 Wintering effect on simulated live weight of Hereford cows

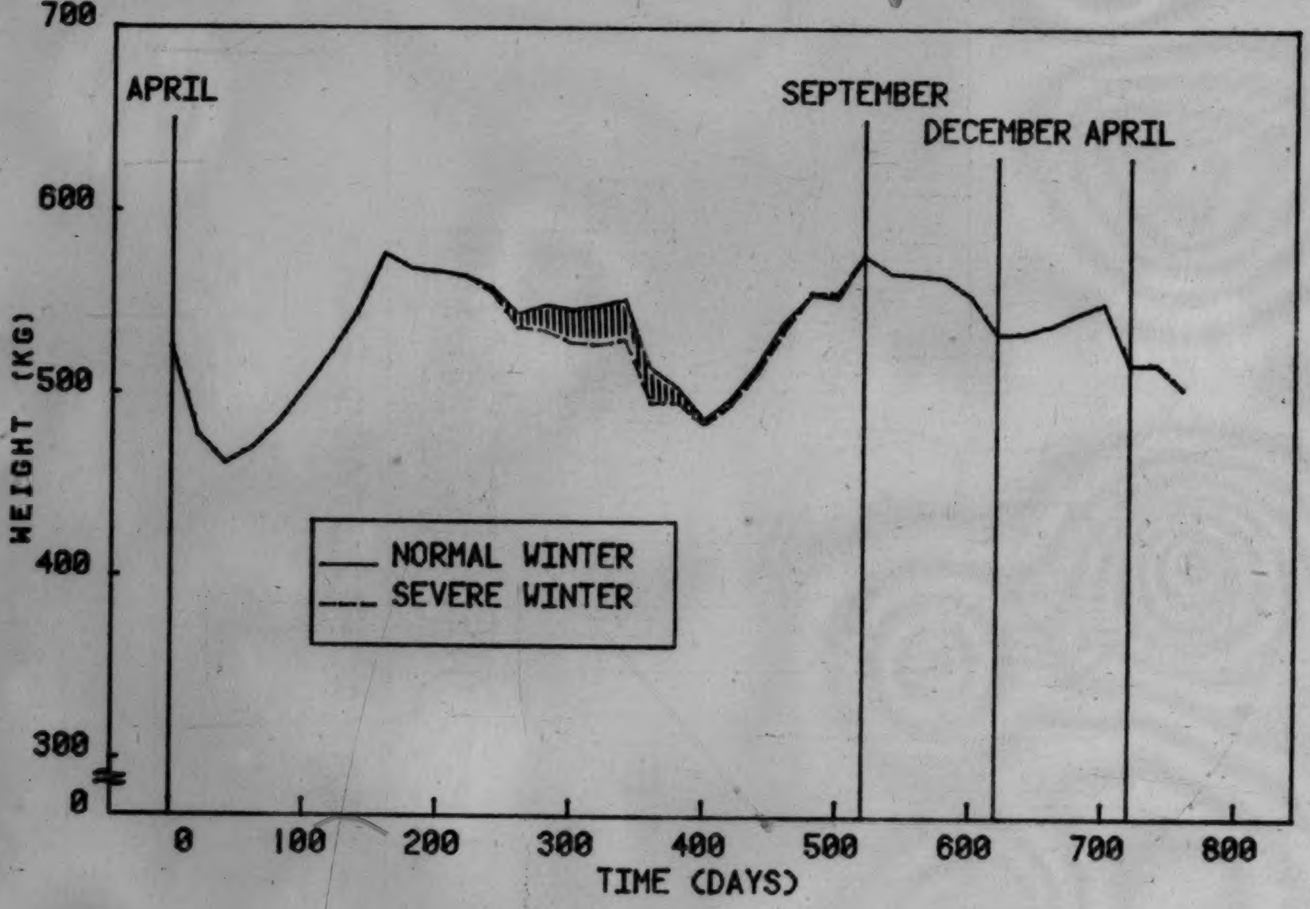

Figure 5.3 Wintering effect on simulated live weight of Beef Synthetic cows

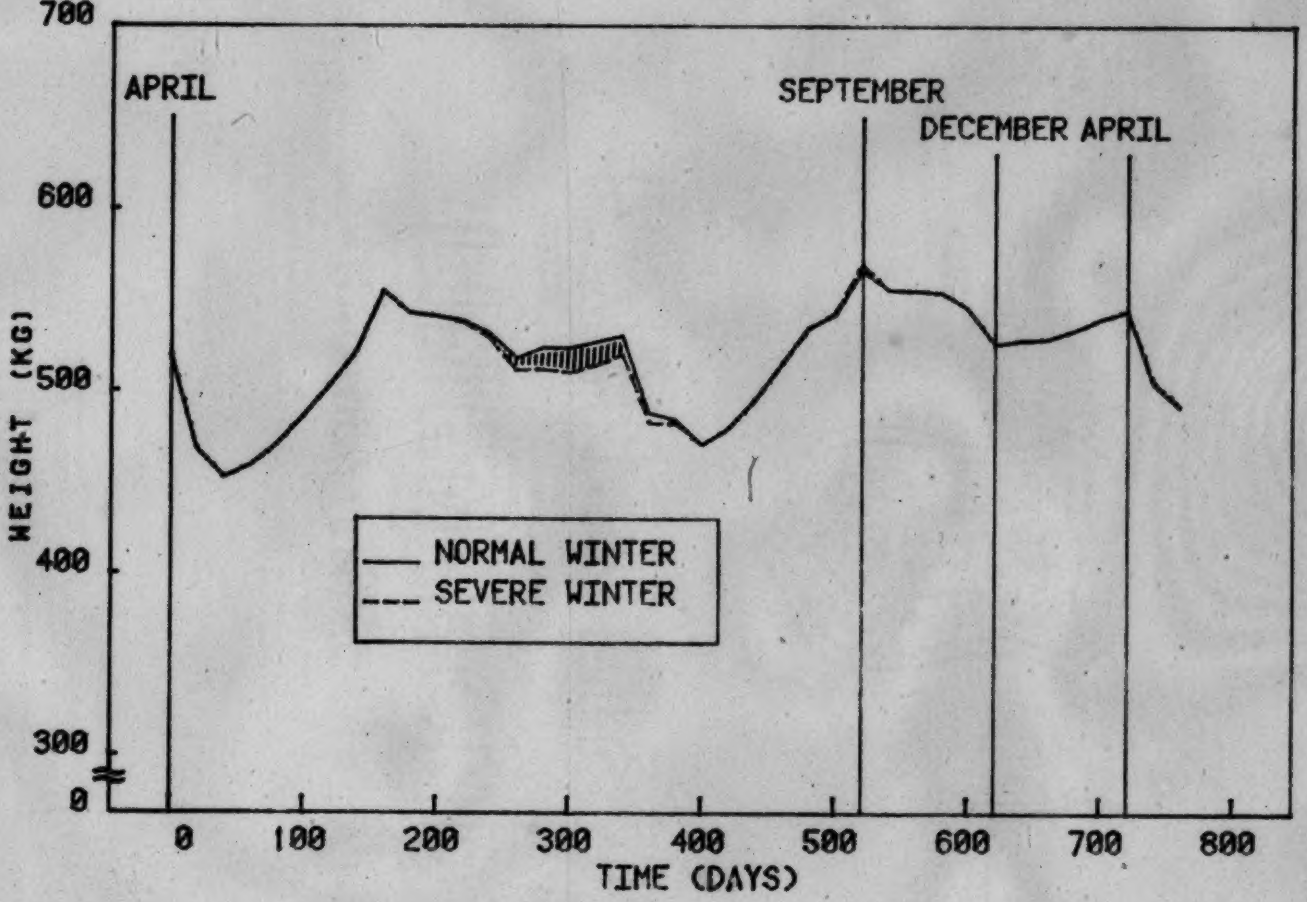

Figure 5.4 Wintering effect on simulated live weight of Dairy Synthetic cows

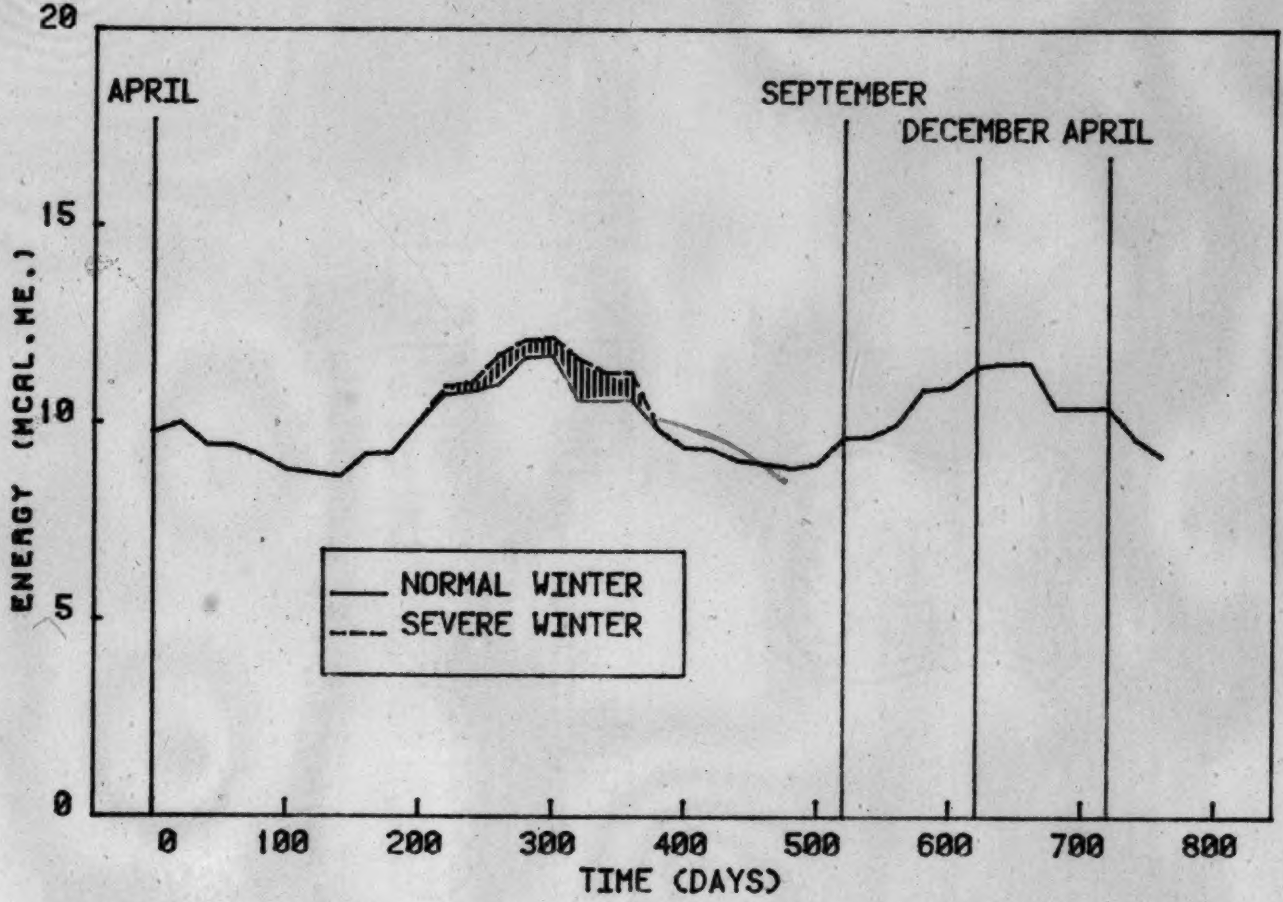

Figure 5.5 Wintering effect on simulated maintenance requirements of Hereford cows

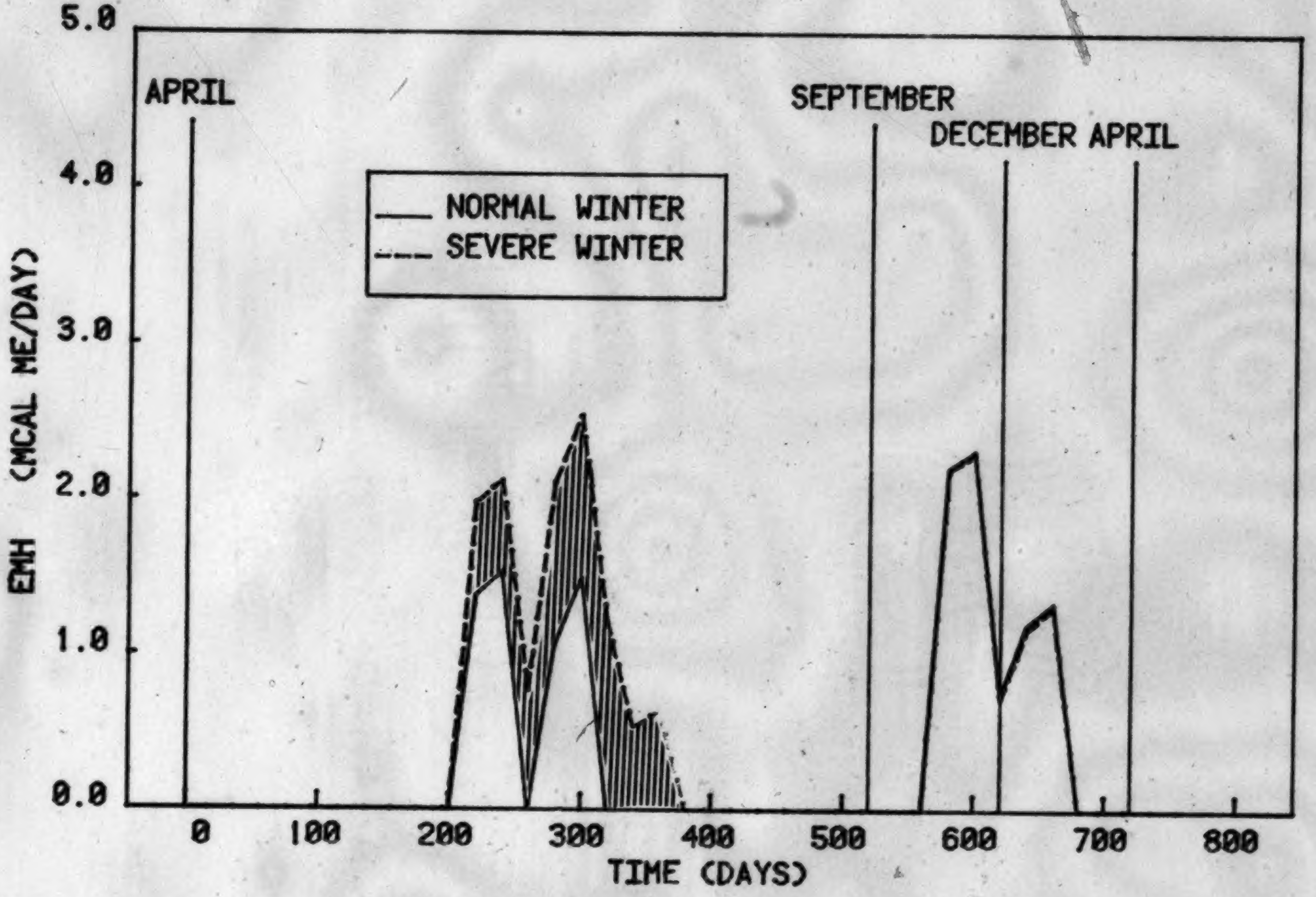

Figure 5.6 Wintering effect on simulated marginal heat production below the thermoneutral zone of Hereford cows

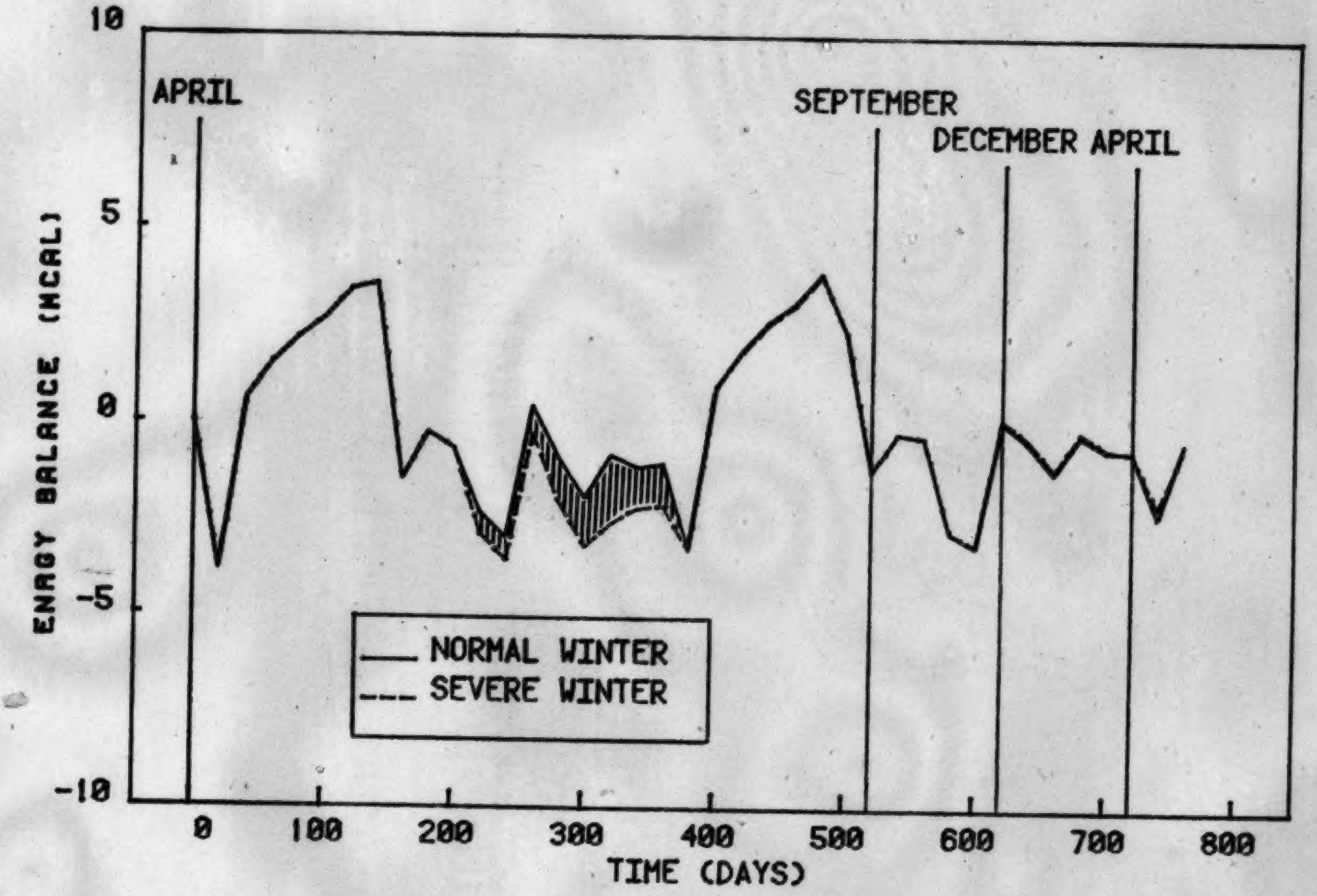

Figure 5.7 Wintering effect on simulated energy balance of Hereford cows

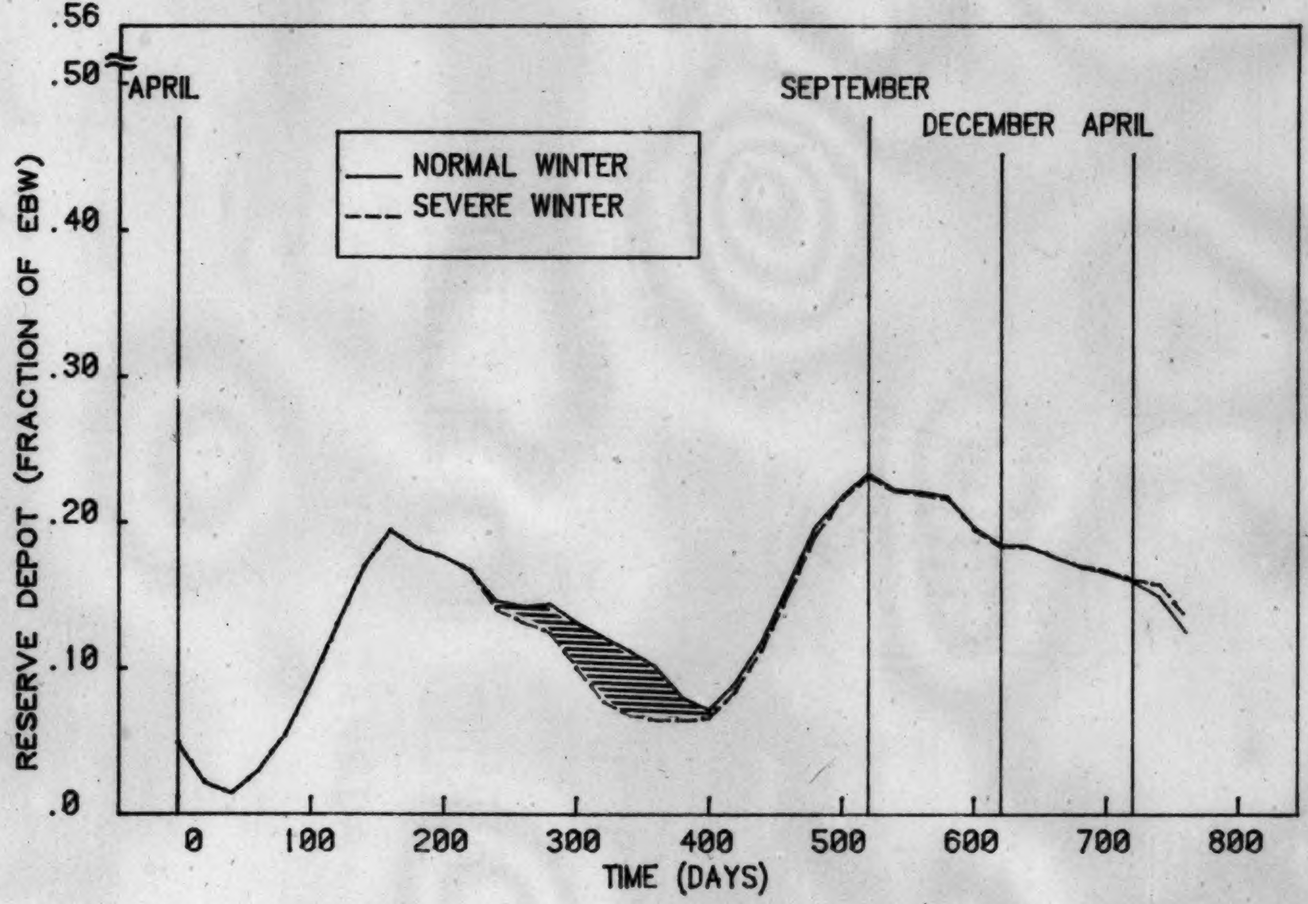

Figure 5.8 Wintering effect on simulated reserve depot of Hereford cows

5.5 CONCLUSIONS

Under the management practices prevailing at The University Ranch, the model predicts that the simulated effect of severe winters on change in weight of beef cows is only a temporary one, and cows were predicted to recover from mid-winter weight loss during the following grazing season.

Some reduction in predicted empty body weight is derived from a change in reserve tissue which recovers more slowly. Therefore, fertility can be damaged if cows are not compensated in the winter for catabolism of reserve tissue. Fertility is predicted to be affected by cold winters to a greater degree than is weaning weight.

Beef synthetic cows under cold winter conditions are predicted to lose in fertility and weaning performance more than the other two groups, due to large loss of reserve. Nevertheless, they manage to maintain a better degree of fertility than the other groups.

Even though dry matter consumption is not changed over the winter due to management constraints, predicted digestibility tends to decrease due to increases in the rate of passage.

Simulated maintenance and heat production requirements are likely to increase under severe winters. The increase in maintenance is not always connected directly to the change in temperature, but depends fairly strongly on size and condition. Small cows as Hereford are predicted to spend relatively more energy on maintenance and less on heat production, whereas **SY** and **DY** are predicted to spend less on maintenance and more on heat production.

Energy balance in cows on limited intake is directly influenced by the increase in maintenance and heat production expenditures. Thus, the more marginal the energy balance during normal winters, the more severe will be the deficit during a harsh one. Since fat tends to be catabolized under energy deficiency, increases in energy expenditures will cause a depletion of this tissue. Hereford, and **SY** cows are predicted to lose more reserve tissue during severe winters than are **DY** cows.

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6. ANALYSIS OF THE SIMULATED INCORPORATION OF DAIRY CATTLE TYPE INTO BEEF SYNTHETIC BREEDS UNDER ALBERTA CONDITIONS

6.1 ABSTRACT

A deterministic computer simulation model was used to study the effect of change in milk potential through change in initial milk yield (**IPDYM**) and persistency (**P**) on body weight, feed intake, milk production, energy balance and level of production and reproduction of range cows.

Six treatments combining different levels of **IPDYM** with constant levels of **P** and different levels of **P**, with constant levels of **IPDYM** and a combination between the two were compared with a control, which was represented by the Dairy Synthetic cows at The University of Alberta Ranch.

Significant differences were found in the simulation of 180 day calf weight. An increase of 9.5 kg in **IPDYM**, increased predicted 180 day weaning weights by 22.1 kg, whereas an increase in **P** by 56%, increased predicted 180 day weaning weight by 6.9 kg.

Lines with greater **IPDYM** were predicted to have some advantage in dry matter intake. Thus, they consumed more energy and recovered from calving faster than did lines with low **IPDYM**. Consequently, high **IPDYM** lines had some fertility advantage over the other lines.

Predicted milk production and calving performance were improved to a greater extent by increasing **IPDYM** than by

improving **P**. Increasing **IPDYM** also lead to the predicted peak point in the lactation curve being moved further from the begining of the lactation. Total predicted milk loss (due to enviromental conditions preventing potential maximum milk production being realized) increased as the **IPDYM** or **P** were increased. Taking all these results into consideration, it was concluded that selection for increase in **IPDYM** is predicted to be preferable over selection for improvement in **P**.

6.2 INTRODUCTION

Interest in the use of dairy breeds in crossbreeding with beef breeds has increased in recent years. It has been shown that the amount of milk produced by the dam is very important for the growth of its calf in its initial stage of life (Deutscher and Whiteman, 1971; Spelbring *et al.* 1977; Butson 1981; Arthur, 1982). Nevertheless, only few workers have investigated lactation curves in beef cows, while lactation curves in dairy cows have been studied extensively (Gains, 1927; Woods, 1961).

As discussed by Gleddie (1965) and Melton *et al.* (1967) it is obvious that there are differences in initial milk yield and presistency among beef and dairy breeds. Gains (1927) in an extensive study on the persistency of lactation in dairy cows reported a persistency of 0.37 to 0.52 percent in Guernsey and Holstein-Friesian cows with intial milk yield of about 20 kg/day. Sanders (1977) in a simulation model used a persistency of 0.8% and considered it to be a general value for beef cows. In the present study where data from Butson (1981) were analyzed, initial milk yield was found to be between 9.26 and 10.47 kg/day, while persistency was found to range from 0.8 to 1.3 percent for the described breeding groups (Appendix-2).

Selection criteria in dairy breeding programs have emphasized total milk volume and persistency (Gains 1927). It is clear that increases in milk volume can be obtained by either an increase in initial milk yield or improvement in persistency. For dairy cows with relatively high initial daily milk yield fed to their yield and yielding to their potential, persistency was found to be a better criterion for selection. For range beef cows with relatively low initial daily milk yield, fed to their pasture availability, and yielding to their calf capacity, it is not clear what selection criteria would be best suited.

Ever since dairy breeds were introduced into the beef crosses at The University Research Ranch in 1968, there has been an increase in initial milk yield and an improvement in persistency (Gleddie, 1965; Butson, 1981). Practically, it is quite complicated to evaluate these parameters in a breeding program. Simulation modelling on the other hand has been found to be a useful approach.

Using the simulation model (Chapter 3) to evaluate environmental effect on lactation potential and cow productivity via change in IPDYM or P, can help in the evaluation of those selection criteria.

Hence the objectives of this study were:

1. to use a simulation model to analyze a system in which the genetic potential of the lactation is increased, either by change in initial milk yield or persistency, and to study cow simulated production under environmental conditions typical of Alberta,
2. to investigate the effect of milk potential on the shape of the simulated lactation curve, and
3. to investigate what lactation selection criteria for beef cows are suited to Alberta condtions.

6.3 MATERIALS AND METHODS

6.3.1 The Model

The Beef Cow Production Model (COW.82) and the Fertility Routine (FER.82) (Chapter 3) were used to simulate cow performance and reproduction. The model simulates growth, feed intake, milk production and reproduction as a function of genetic potential of an average mature beef cow, environmental conditions, feed quality and feed availability. Model equations represent a general relationship among the variables and do not directly consider breed effect.

Energy requirements are expressed in Mcal **ME**. The nutritional environment is defined by crude fiber concentration in the available feed, whereas demand for protein, vitamins and minerals is assumed to be met.

The model is programmed to complete at least two full annual cycles. In the first, initial conditions are set on the basis of literature estimates, so that only in the second cycle are initial conditions set by the model.

Environmental conditions are set to those prevailing at the University Ranch in the years 1976-77.

6.3.2 Management and Climate

Cows are bred mainly in July-August and calve in April-May. the cows are on the range year round and depend on natural grazing except for four months in the winter when supplementary feed is provided. Weaning occurs 180 days after calving. The climate is cool subhumid, whereas winters are long and cold. Summers are short and warm, and rainfall is low and variable (Berg, 1975).

6.3.3 Experimental Procedures

The general input conditions were the same as those in Chapter 3, except for the parameters which define milk potential. The combination of initial milk yields and persistency as was simulated in the different experiments is presented in Table 6.1.

Table 6.1 The experimental design

Treatment Number	IPDYM kg	P
Control	10.5	0.0938
0	12.0	0.0938
1	15.0	0.0938
2	20.0	0.0938
3	10.5	0.0800
4	10.5	0.0600
5	15.0	0.0700

6.4 RESULTS AND DISCUSSION

NOTE: The results discussed in this section are those predicted by the model. The detailed timing index for the graphs is illustrated in Appendix-5.1.

6.4.1 Calving and weaning

Simulated results of calving and weaning are presented in Table 6.2. As expected calf growth was affected significantly at all stages by the change in milk potential. As the **IPDYM** varied from 10.5 in the control to 20.0 kg in Treatment 2, weaning weight of calves was predicted to vary from 227.3 to 249.4 kg, and average daily gain from 1.033 to 1.155 kg/day. It is well known that calves from dams with dairy breeding, tend to exhibit higher weaning weights than those in other beef crosses (Brown *et al.*, 1972; Wyatt *et al.*, 1977; Butson, 1981).

The estimated interval from calving to conception was also affected significantly by the changes in **IPDYM.** A 19 day decrease in calving interval was simulated when **IPDYM** was varied from 10.5 to 20 kg/day. These results contradict results reported by Deutscher and Whiteman (1971) and Bair *et al.* (1972), who reported some problems in reproduction in high producing cows. This suggests that the high potential cows with small calves do not realize their full potential. thus, calf milk consumption remains low and part of the produced milk is reabsorbed by the cow. In those studies where problems in reproduction were observed milk production

Table 6.2 Simulated calving and weaning results of beef cows with different levels of milk potential (as defined by the initial milk yield and the persistency of lactation).

Item		Calving					Weaning		
		Distribution			Rate	Interval	Weight	A.D.G	Rate
IPDYM	P	%			%	days	Kg	Kg/day	%
kg		30*	60*	90*					
10.5	0.0983	50.0	78.9	82.1	82.1	370	227.3	1.033	76.3
12.0	0.0983	50.8	80.2	83.5	83.5	367	235.3	1.108	77.7
15.0	0.0983	56.5	89.1	92.7	92.7	355	244.9	1.130	86.2
20.0	0.0983	58.9	92.1	95.0	95.0	351	249.4	1.155	90.0
10.5	0.0800	49.5	78.2	81.3	81.3	375	230.1	1.050	75.6
10.5	0.0600	49.4	78.0	81.1	81.1	382	234.2	1.072	75.4
15.0	0.0700	56.5	89.1	92.7	92.7	355	247.6	1.147	86.2

* days from first calving.

was measured as milk consumption of the calf. However, in the Kinsella project no substantial differences in reproduction were found between **HE** with low milk potential, and **DY** with high milk potential (Berg, 1978; Butson, 1981).

The predicted change of weaning weight and of calving interval as **IPDYM** increased, took place at a diminishing rate as shown in Figure 6.1. That means an exponential increase or decrease with increase in **IPDYM**.

Since calving distribution and rate in the fertility routine **FER.82**) are directly connected to the interval taken from calving to conception in the cow production model (**COW.82**), the calving distributions were simulated in accordance with the different rates among the **IPDYMs**. As **IPDYM** varied from 10.5 to 20 kg/day, the calving rate varied from 82.1 to 95.0 percent (the maximum calving rate imposed by the model). Due to the decrease in the open-days interval, calves had more time for growth in the period from calving to weaning, so that the predicted unadjusted weaning weight was increased by: 3.3, 16.9 and 21.9 kg in cows with **IPDYM** of: 12.0, 15.0 and 20 kg/day, respectively, as compared to the 10.5 kg/day control.

As the **P** varied from 0.0938 in the control to 0.060 in treatment 4, predicted weaning weight of calves varied from 227.3 to 234.2 kg, and average daily gain from 1.033 to 1.072 kg. The interval from calving to conception was also affected by the change in **P**, a 12 day increase in calving interval was simulated when **P** was varied from 0.0938 to

0.0600 (Figure 6.2).

Increase in either **IPDYM** or **P** lead to an increase in milk potential. But while in the former calving interval was shortened, in the latter calving interval was lengthened (Figures 6.1 and 2). The reason for these differences in calving interval can be attributed to the different pattern of reserve depot simulated for the Treatments 1, 2 and 4. (Figures 6.15 and 16).

Relatively low calf milk capacity in cows with high **IPDYM**, enabled them to put on reserve tissue much faster than that of low **IPDYM** cows. It was predicted that cows with a better **P** lost more reserves in prior lactation, so that the process of reserves recovery was delayed. Since the predicted time taken from calving to conception depends on the recovery of reserve tissue after parturition, rate of recovering did affect the calving interval (Chapter 3).

In treatment 5, where both **IPDYM** and **P** were changed by 42 and 34%, respectively, predicted weaning weight was increased by 8.9% and predicted calving interval was shortened by 4.2%. This enabled calves to gain 17.2 kg more than the control by weaning.

6.4.2 Analysis of Change in Weight

The simulated weights of the control and the five treatments over a period of two years is shown in Figures 6.3, 6.4 and 6.5. In the first year, predicted differences in cow weight between the Treatments 1 and 2 and the control were to the advantage of the treatments in the initial period after calving, but to their disadvantage in the later period which lasted from September to the next calving in April. But by the end of the first year, differences among the groups were predicted for calving interval and for loss in reserve tissue. Consequently, the weight pattern of the treated cows was predicted to be closer to that of the control in the second year (Figure 6.3 and 4). As **IPDYM** increased from Treatment 1 to Treatment 2, the advantage or disadvantage in cow weight in different periods increased too. In other words increase in **IPDYM** lead to a greater predicted fluctuation in cow weight.

In the first year, differences in cow weight between Treatments 3 and 4 and the control group, were to the advantage of the control at all stages, but as **P** improved, the weight advantage of the control decreased (Figure 6.4). In the second year, the differences between Treatments 3 and 4 and the control were substantially reduced. This can be attributed to the difference in dry matter intake controlled by the lipostatic mechanism. As for cow weight in Treatment 5, the relationships with the control were the same as those for Treatments 1 and 2.

6.4.3 Dry Matter Intake

The simulated total and average daily intake of the control and the 5 treatments over a single season are given in Table 6.3. Meaningful differences in dry matter intake

Table 6.3 Simulated dry matter intake of beef cows (over three periods of 40, 100 and 100 days respectively) with different levels of milk potential (as defined by initial milk yield and persistency of lactation).

Item		Period						Total	
		1		2		3			
IPDYM	P	Kg	Kg/d	Kg	Kg/d	Kg	Kg/d	Kg	Kg/d
10.5	0.0983	302.5	7.56	1229.8	9.27	1885.1	6.55	2698.1	7.39
12.0	0.0983	311.8	7.79	1275.0	9.63	1940.0	6.65	2711.9	7.42
15.0	0.0983	329.4	8.23	1311.4	9.82	1950.1	6.38	2638.8	7.38
20.0	0.0983	353.6	8.84	1338.1	9.84	1936.9	5.99	2596.2	7.11
10.5	0.0800	300.9	7.52	1255.3	9.54	1915.3	6.60	2759.2	7.55
10.5	0.0600	299.7	7.49	1256.7	9.57	1920.4	6.63	2804.5	7.68
15.0	0.0700	329.5	8.23	1324.9	9.95	1936.9	6.12	2625.5	7.19

resulted from the simulation of different treatments and time periods within treatment. Periods were comprised of three intervals: 0-40, 41-140 and 141-240 days post-calving.

As **IPDYM** varied from 10.5 to 20 kg/day, predicted dry matter intake (intake) varied from 7.56 to 8.84, 9.27 to 9.84 and 6.55 to 5.99 kg/day in the first, second and third period, respectively. For the season as a whole predicted daily intake varied from 7.39 to 7.11 kg/day, and the maximum intake was predicted when **IPDYM** was somewhere around 12.0 kg/day. Jones *et al*. (1965) in a study of the feed intake of grazing cows during lactation, reported similar variation in intake for high yield, low yield and dry dairy cows yielding 15.5, 13.2 and 0 kg/day and consuming 11.2, 10.6 and 8 kg/day, respectively.

The pattern of the simulated change of average daily intake in period 3 was very different from those in periods 1 and 2. This can be attributed mainly to the fact that the same stocking rate (0.8 animals per acre) was always maintained within a treatment, so that a greater consumption by the high potential cows in an earlier period, left less residual pasture in later periods, and therefore availability was considerably reduced.

Since the study was done in order to evaluate and define the effect of change in milk potential on change in production under identical conditions and assumptions, it was important not to change stocking rate and to let the cows consume the available pasture for the whole period. Due to differences in the dynamics of the pasture removal among the treatments, the predicted total seasonal pasture consumed by the higher potential groups was smaller than that of the lower potential groups (Table 6.3). As mentioned, this was because the high potential cows depleted the pasture early on, thereby leaving very little for later stages.

The pattern of the simulated daily intake of Treatments 1 and 2 and of the control group over a period of 2 years is shown in Figure 6.6. In periods 1 and 2 daily intake was greater in Treatment 2 than in 1 and greater in 1 than in the control. But due to the lipostatic effect in Treatment 2, daily intake was reduced towards the second period, and this reduction in daily intake caused the average accumulated daily intake of Treatment 2 to reach the same level as that of cows with a lower potential as in Treatment 1. As for the third period, fairly low pasture availability forced daily consumption to decrease over time, and consequently the accumulated and the overall average daily intake were reduced (Table 6.3).

The advantage in daily intake that Treatment 2 had over both treatment 1 and the control in the initial period was attributed to the fact that because of their superior lactation ability, it was assumed in the model (ARC, 1980) that these cows had the aptitude to consume more dry matter than cows with inferior lactation ability. This rate of increase in intake and therefore of energy intake was found to be greater than that of energy requirements for the additional milk produced by these cows. Thus, these cows were predicted to put on fat, so that in terminal stages they lost appetite and reduced consumption.

As P varied from 0.0938 to 0.0600, predicted average intake varied from 7.56 to 7.49, 9.27 to 9.57 and 6.55 to 6.63 kg/day in the first, second and third period, respectively. For the season as a whole, predicted average intake varied from 7.39 to 7.68 kg/day. Average daily intake in period 1 was predicted to decrease, whereas in periods 2 and 3 it was predicted to increase. Thus, the overall daily intake followed the same pattern as in periods 2 and 3 (Table 6.3).

The simulated daily intake of Treatment 3 and 4 and the control group over a period of 2 years is shown in Figure 6.7. As illustrated the simulated pattern daily intake was not influenced by change in P and all three groups consumed similar amounts of dry matter. The results for Treatment 5 are illustrated in Figure 6.8. The change of intake in this treatment was found to follow the same pattern as in Treatment 1.

6.4.4 Milk Production

Simulated total and average daily milk production and milk losses (loss due to energy deficit + loss due to past effect (**RDYM+DEF**)) in the control and the five treatments over a single season are given in Table 6.4. Substantial

Table 6.4 Simulated milk yield and milk loss of beef cows with different levels of milk potential as defined by initial milk yield and persistency of lactation.

Item		DYM		RDYM		DEF	
IPDYM	P	Kg	Kg/d	Kg	Kg/d	Kg	Kg/d
10.5	0.0938	1294.1	7.1	19.5	0.108	42.0	0.233
12.0	0.0398	1432.8	7.9	22.1	0.122	44.6	0.248
15.0	0.0938	1635.1	9.1	19.5	0.108	45.3	0.252
20.0	0.0938	1830.4	10.2	15.3	0.085	46.6	0.259
10.5	0.0800	1351.5	7.5	23.2	0.129	42.0	0.233
10.5	0.0600	1438.7	8.0	23.5	0.130	43.0	0.238
15.0	0.0700	1723.0	9.6	19.5	0.108	46.9	0.260

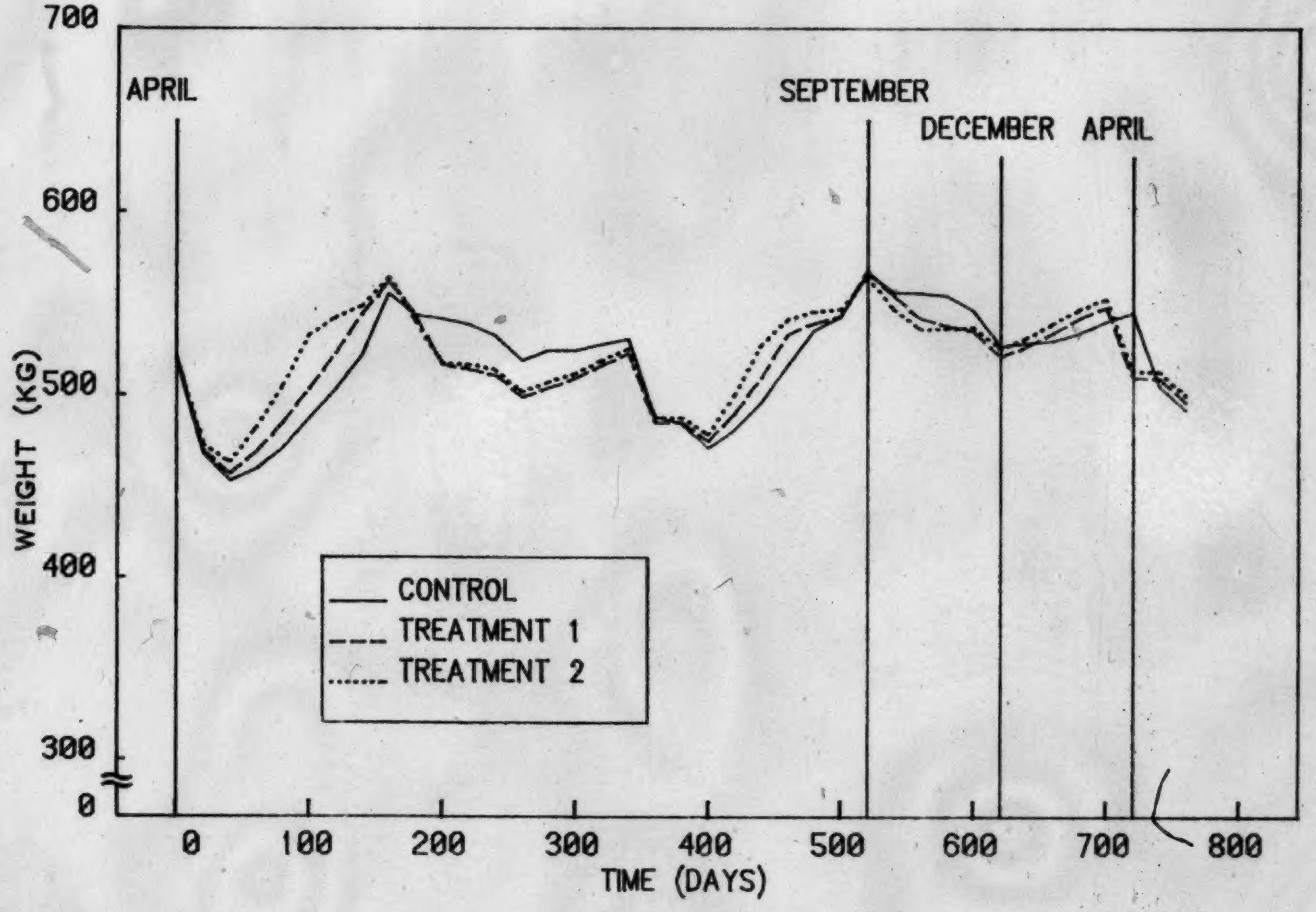

Figure 6.3 Milk potential effect on simulated live weight (treatments 1 and 2)

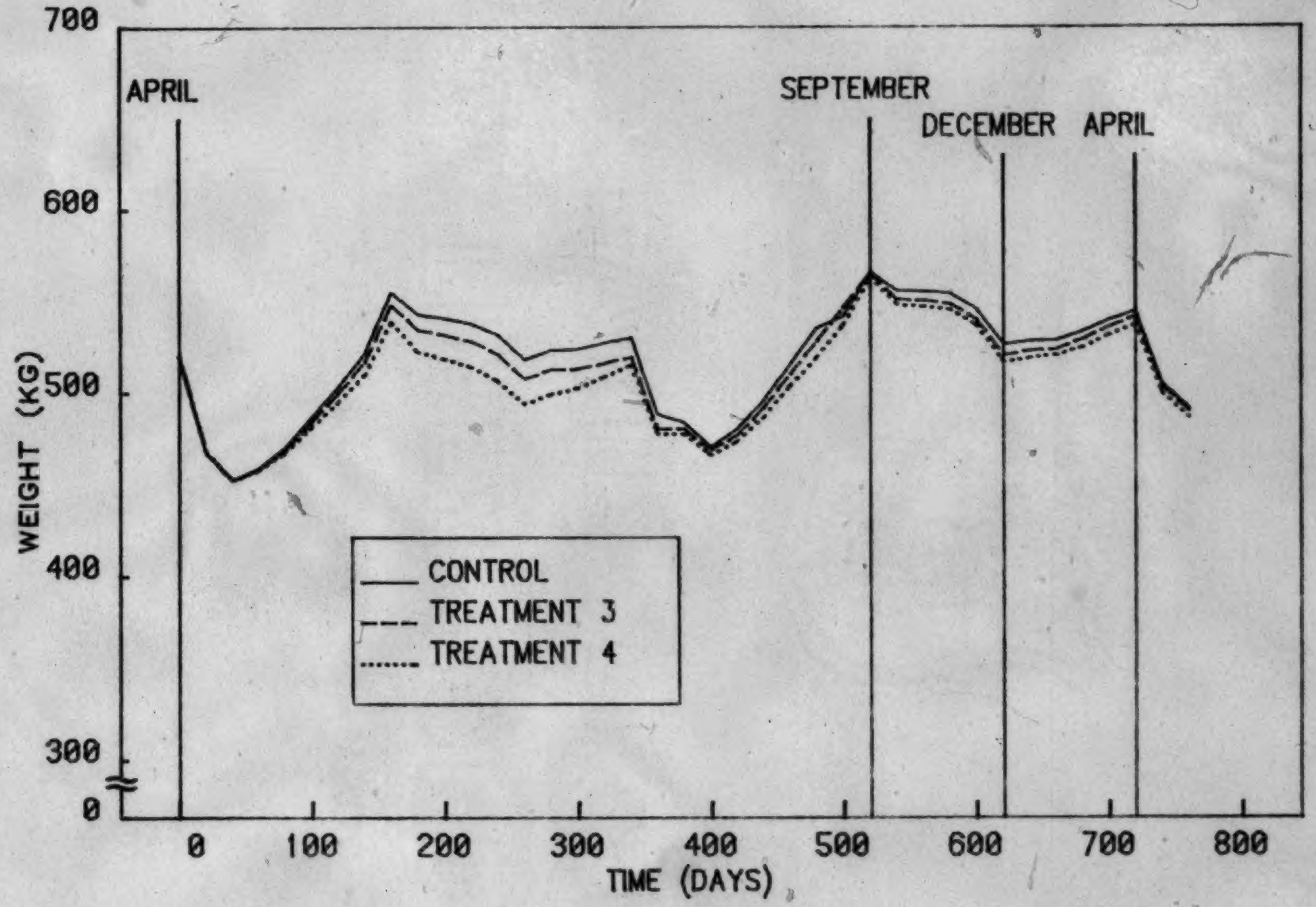

Figure 6.4 Milk potential effect on simulated live weight (treatments 3 and 4)

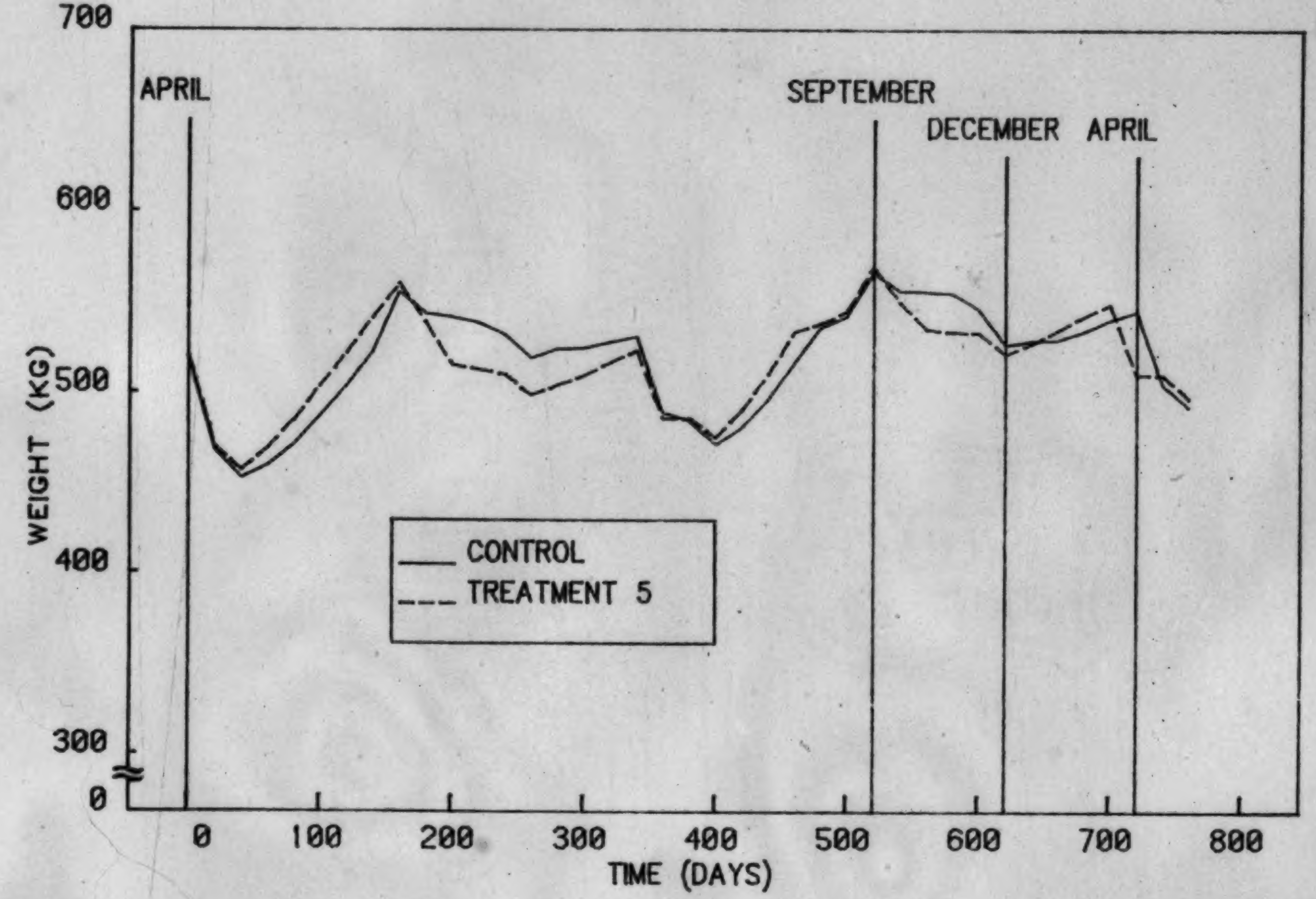

Figure 6.5 Milk potential effect on simulated live weight (Treatment 5)

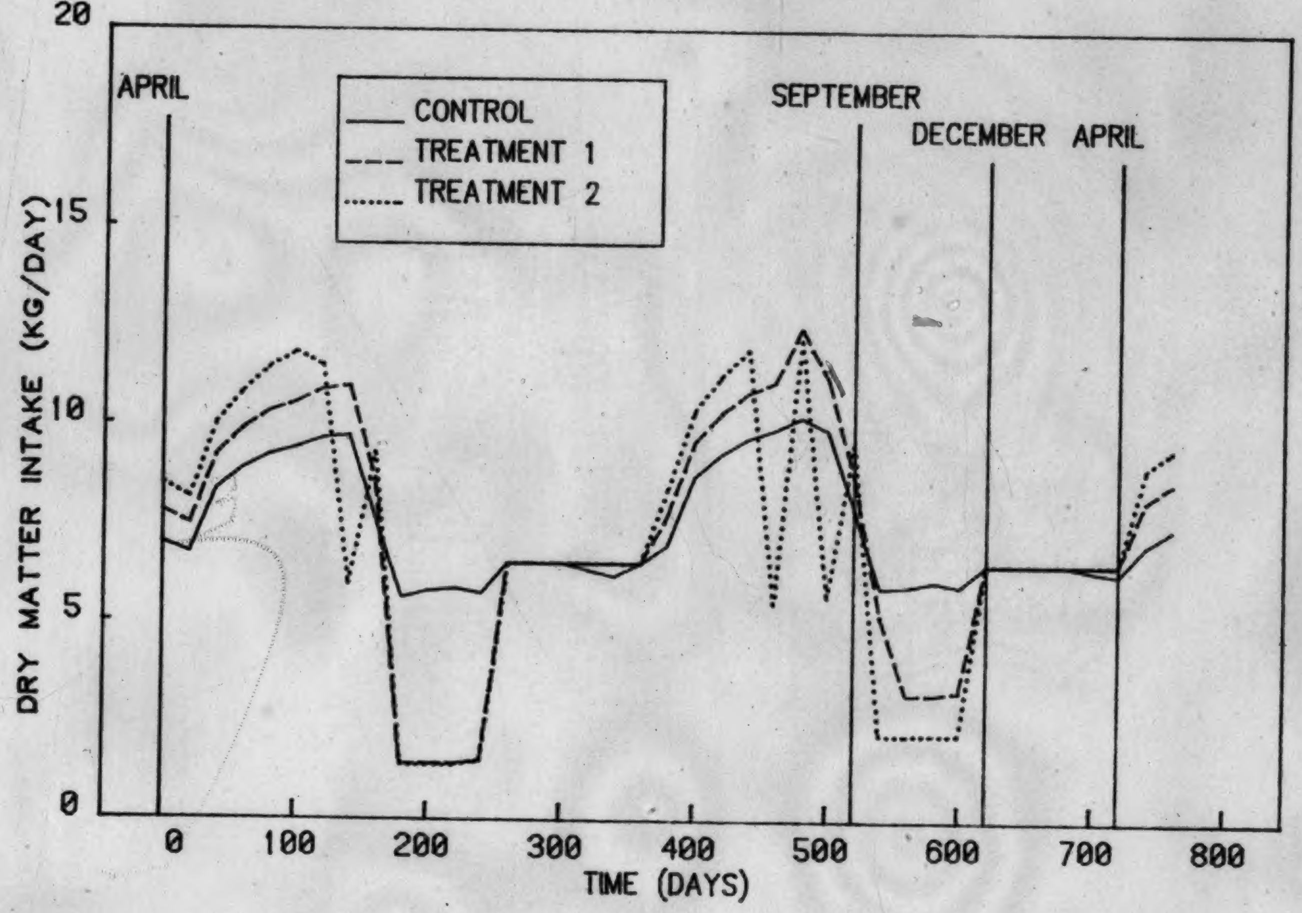

Figure 6.6 Milk potential effect on simulated daily dry matter intake (treatments 1 and 2)

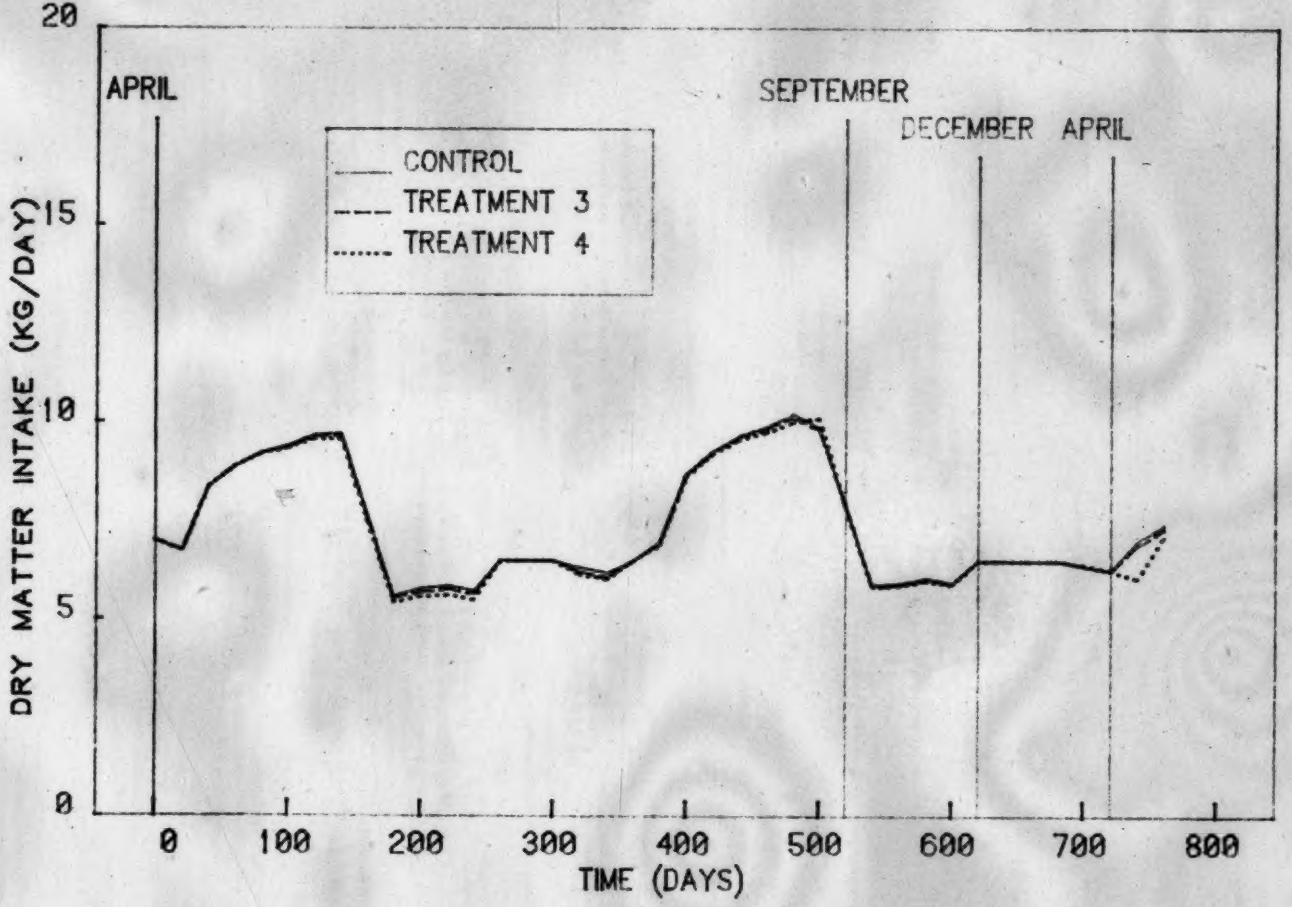

Figure 6.7 Milk potential effect on simulated daily dry matter intake (treatments 3 and 4)

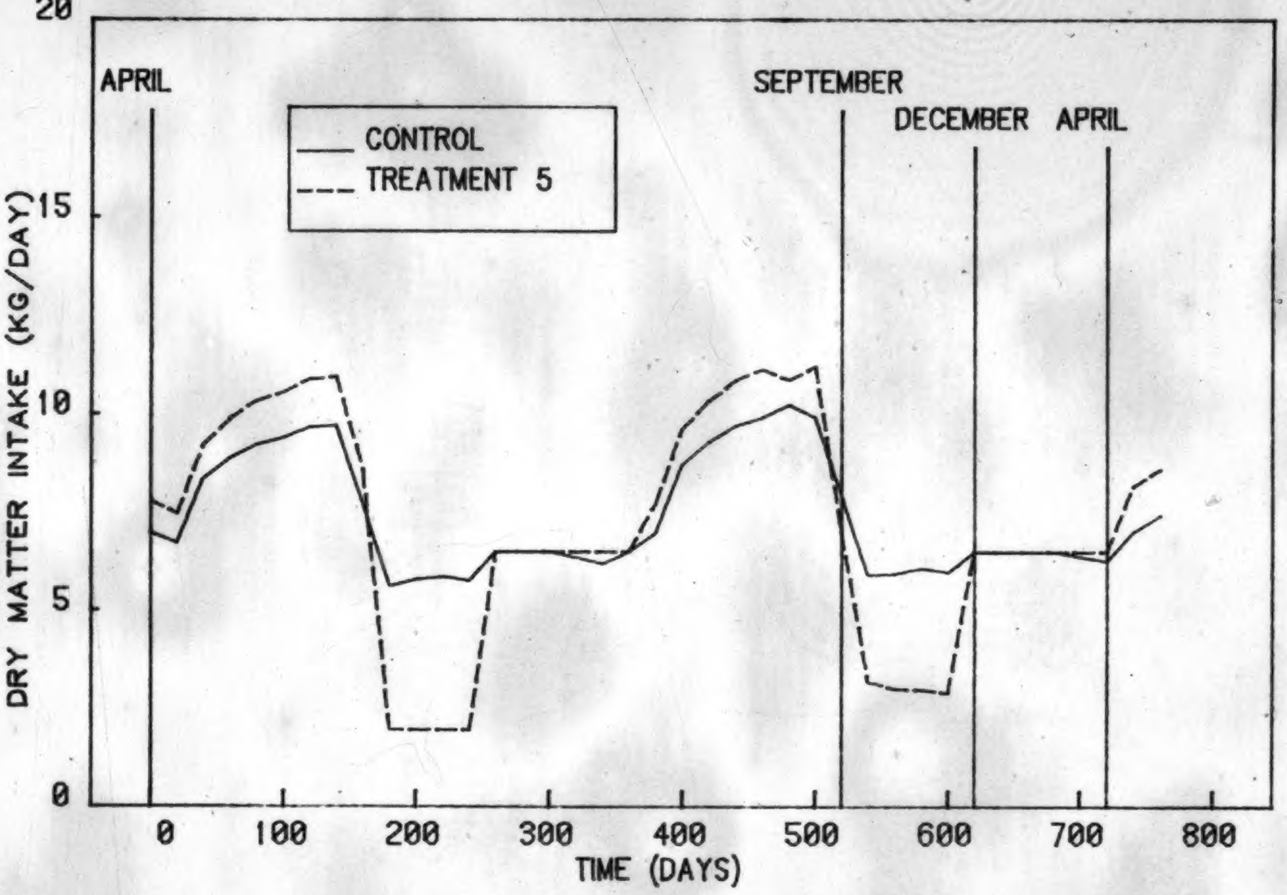

Figure 6.8 Milk potential effect on simulated daily dry matter intake (Treatment 5)

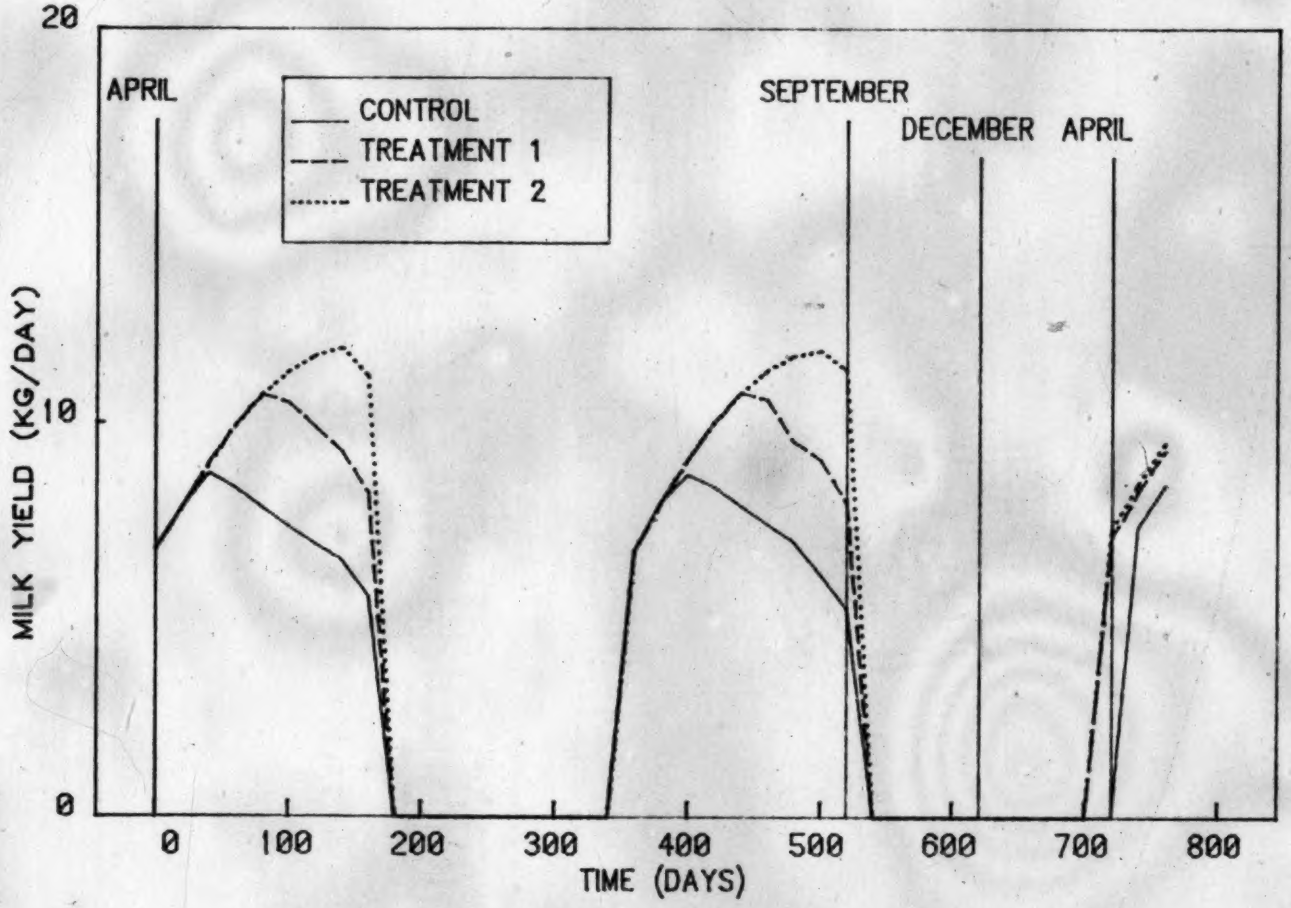

Figure 6.9 Milk potential effect on simulated daily milk yield (treatments 1 and 2)

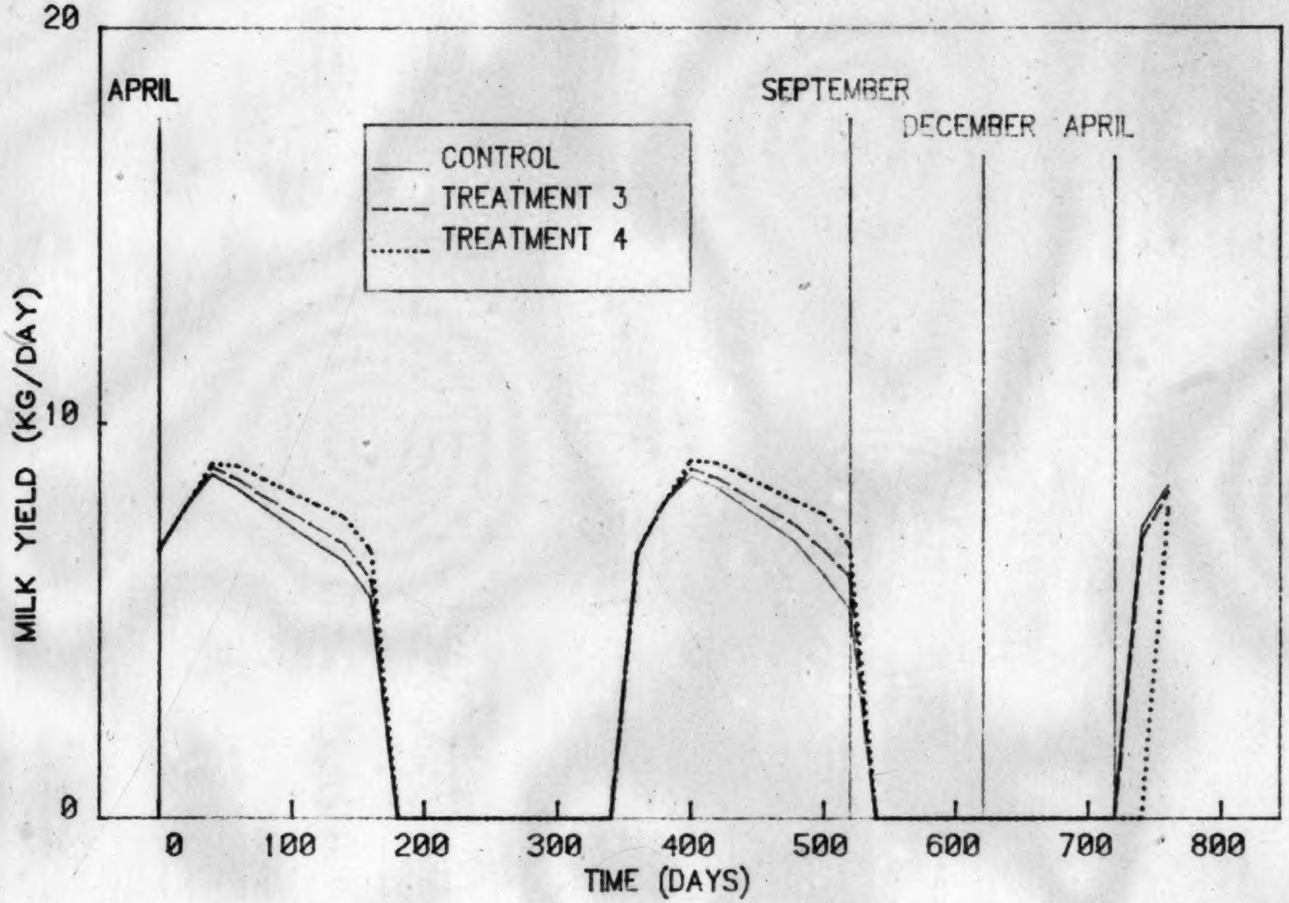

Figure 6.10 Milk potential effect on simulated daily milk yield (treatments 3 and 4)

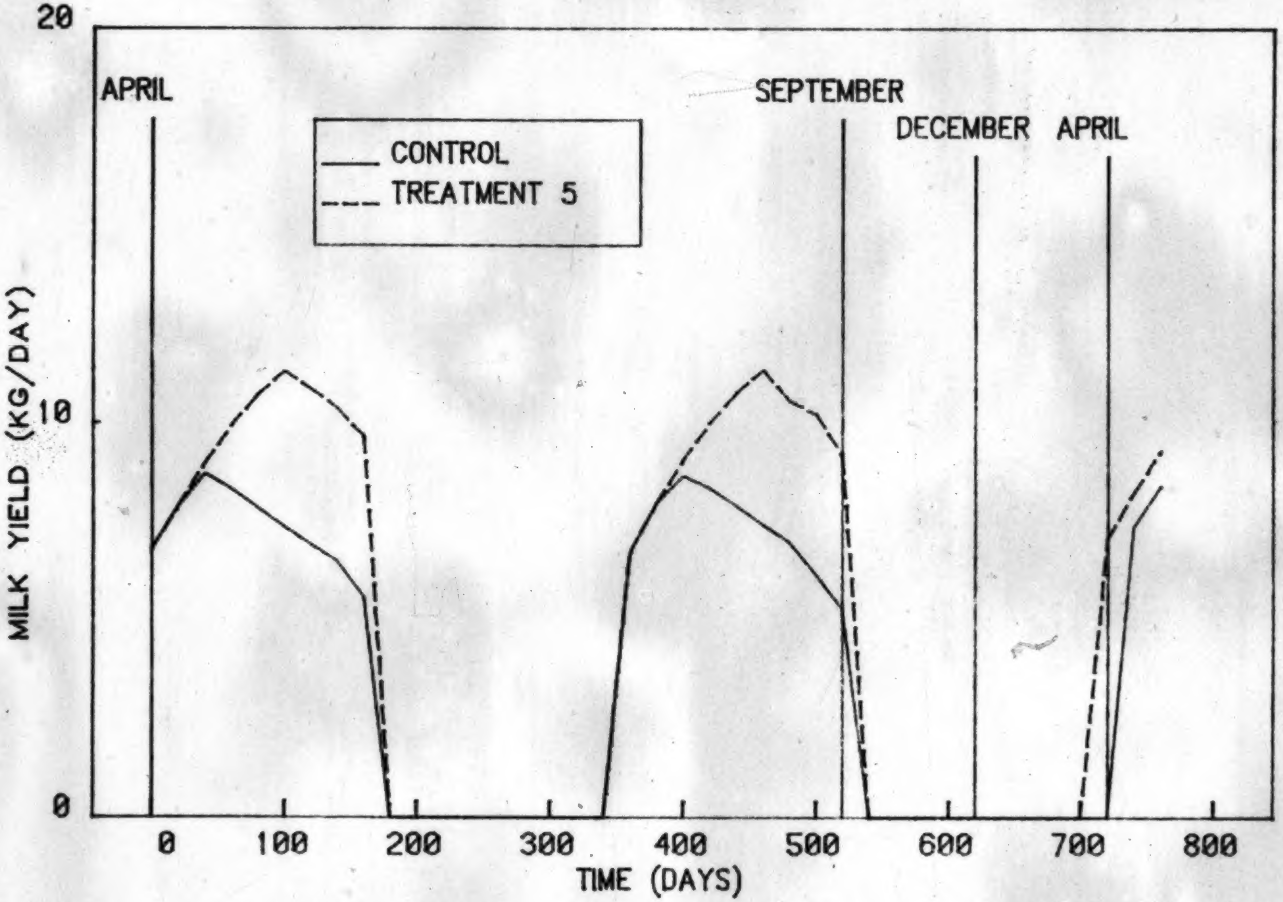

Figure 6.11 Milk potential effect on simulated daily milk yield (Treatment 5)

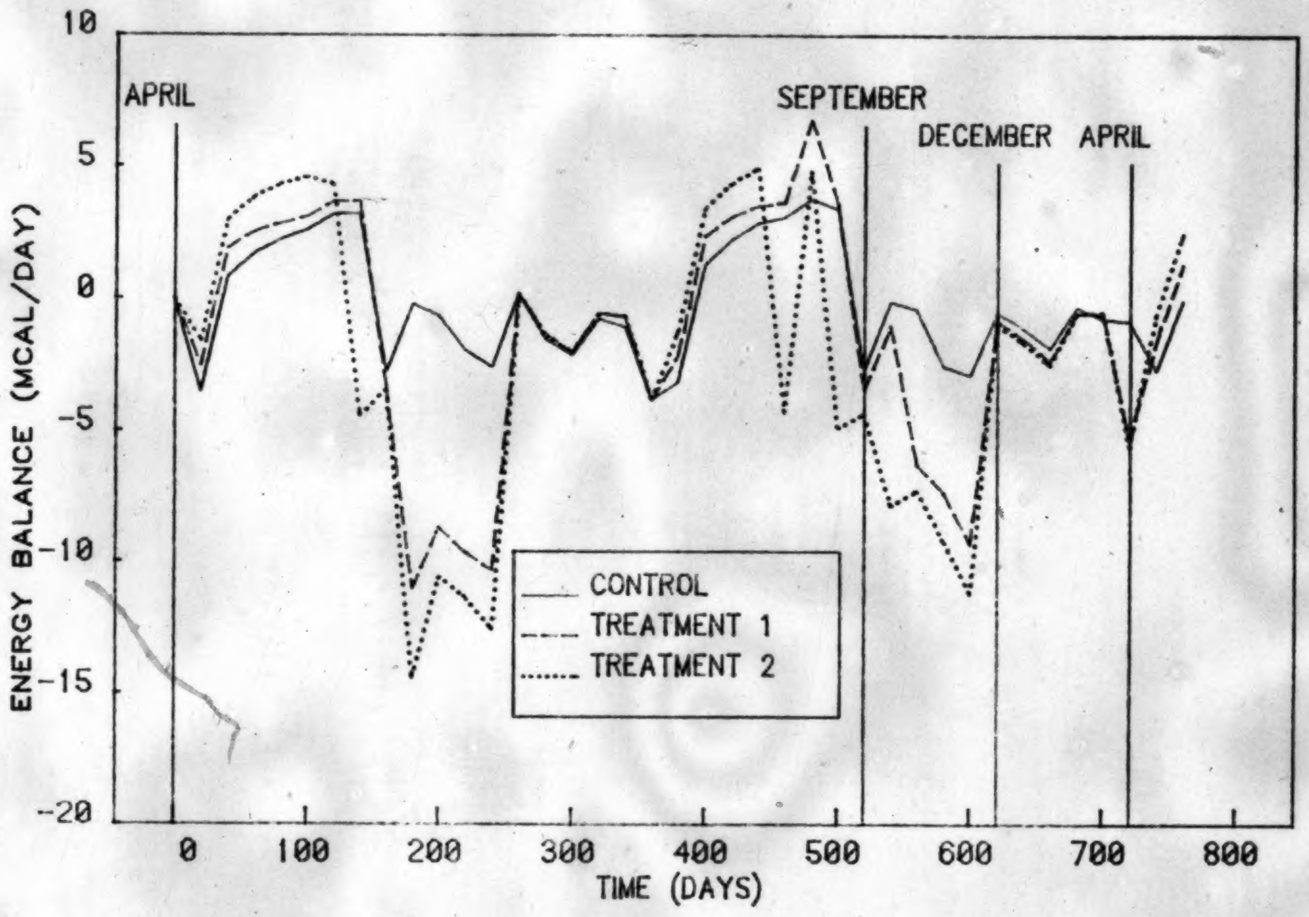

Figure 6.12 Milk potential effect on simulated daily energy balance (treatments 1 and 2)

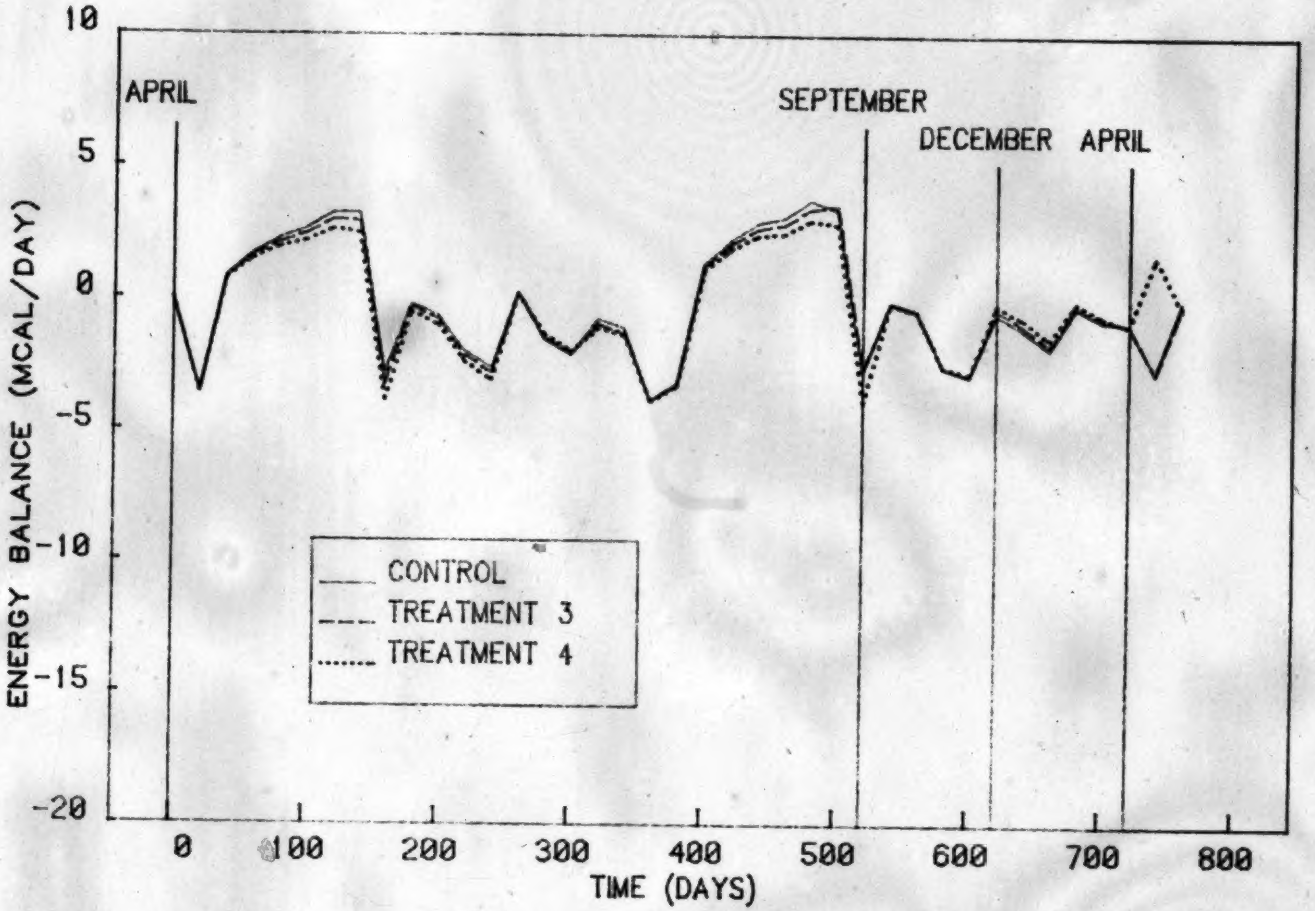

Figure 6.13 Milk potential effect on simulated daily energy balance (treatments 3 and 4)

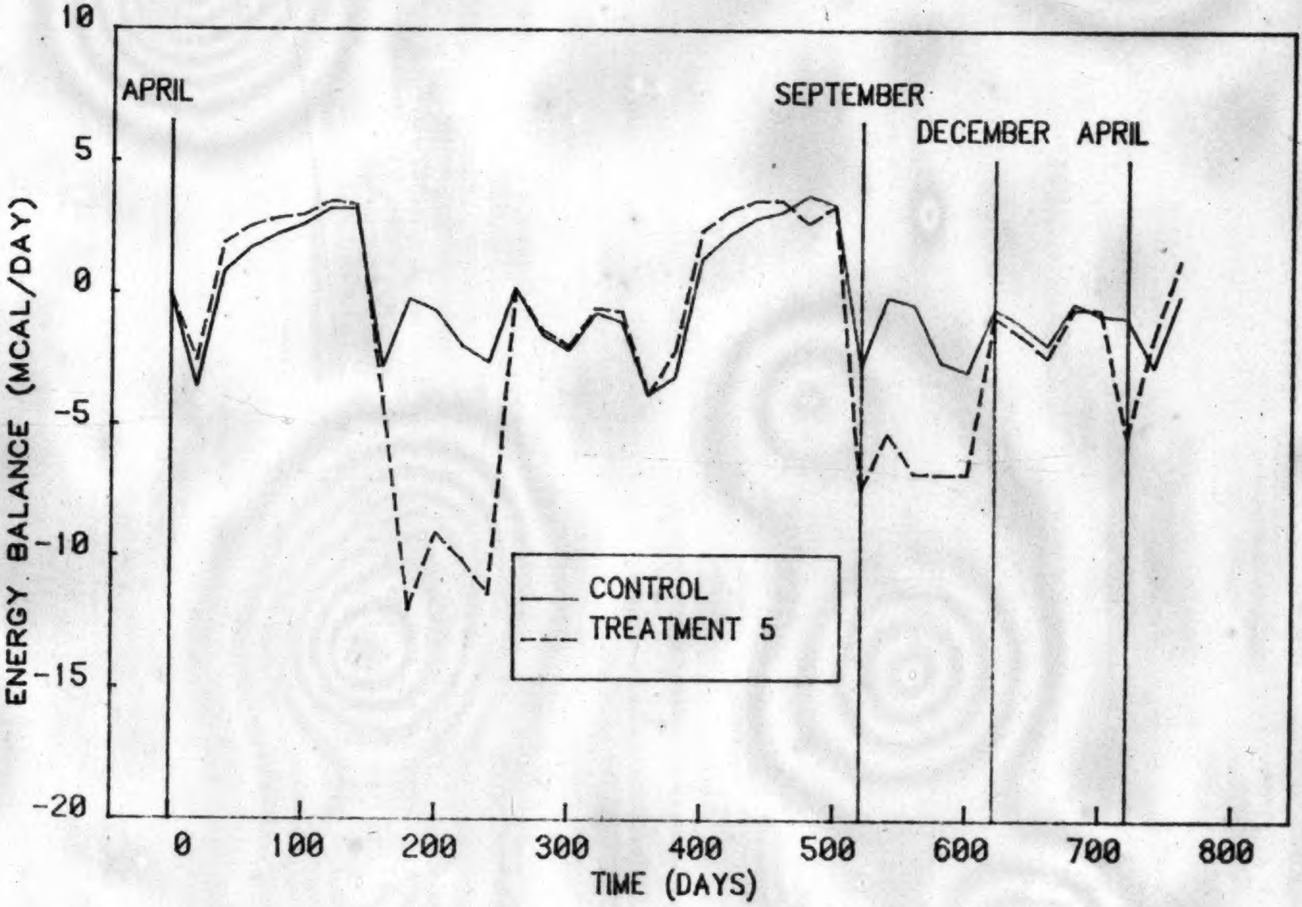

Figure 6.14 Milk potential effect on simulated daily energy balance Treatment 5)

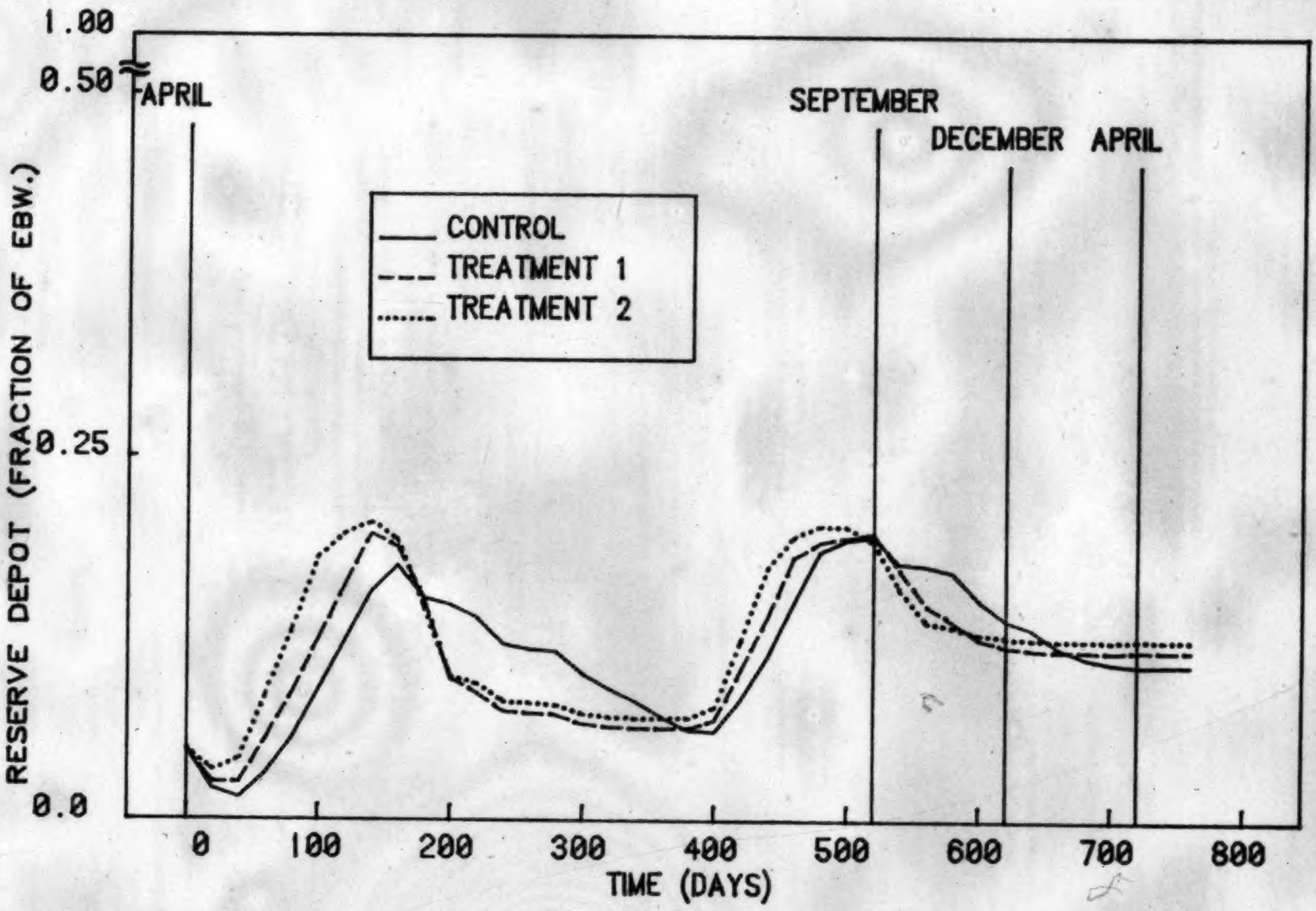

Figure 6.15 Milk potential effect on simulated reserve depot (treatments 1 and 2)

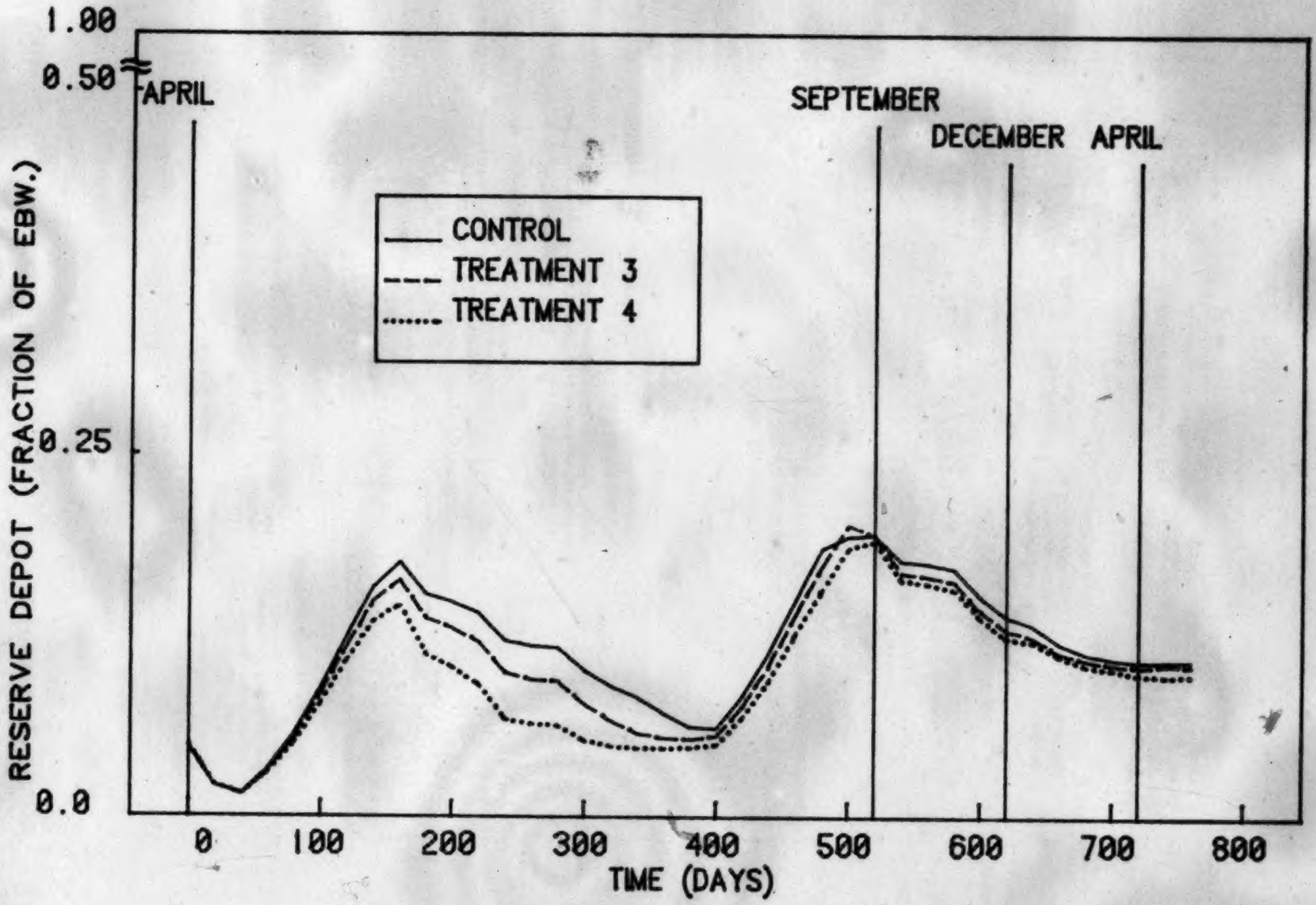

Figure 6.16 Milk potential effect on simulated reserve depot (treatments 3 and 4)

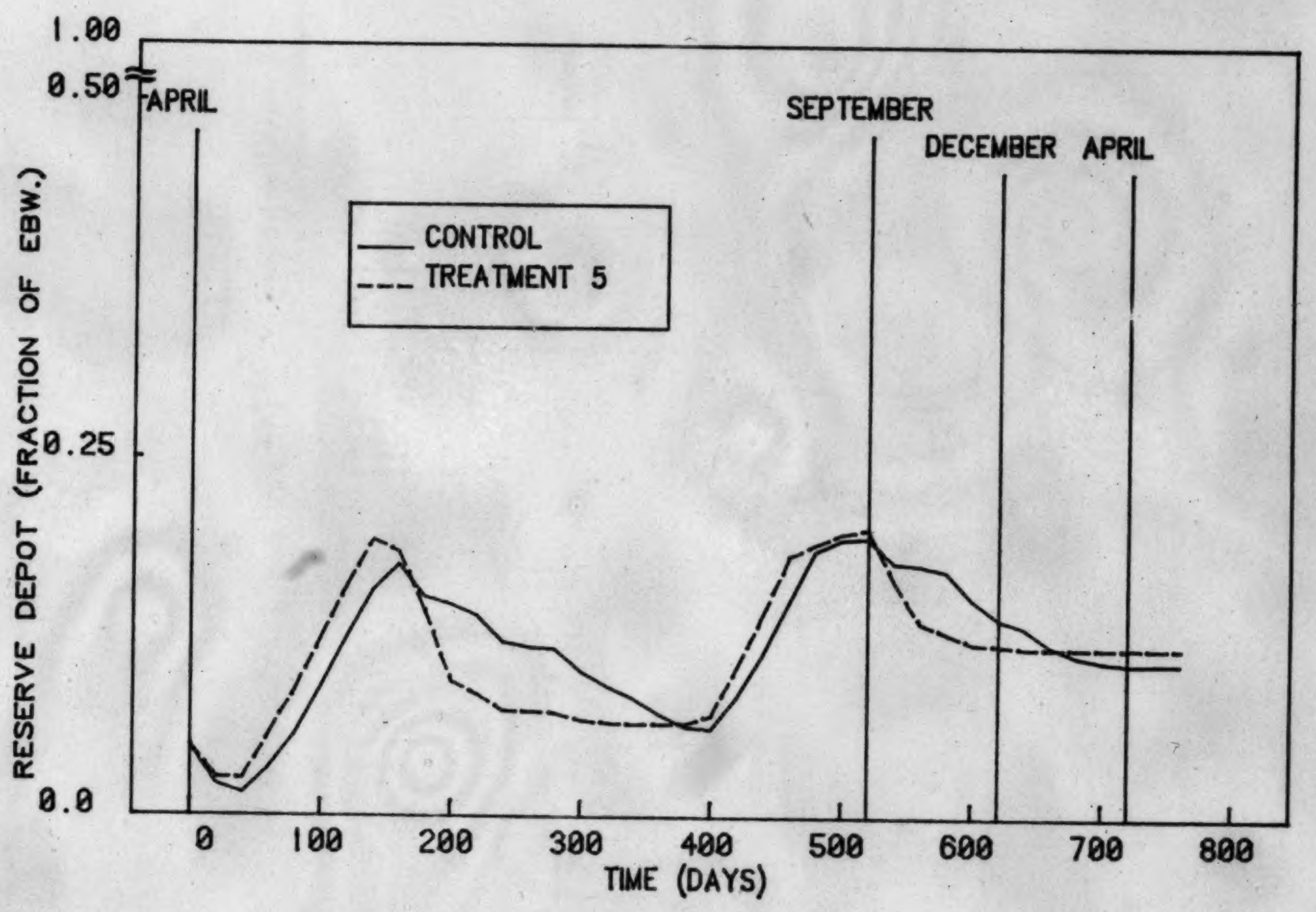

Figure 6.17 Milk potential effect on simulated reserve depot (Treatment 5)

6.5 CONCLUSIONS

Milk production of beef cows under range conditions in Alberta can be genetically improved by increasing initial milk potential or by improving persistency. Manipulating initial milk potential is predicted to be a more effective method of increasing milk production than manipulating persistency.

Improvement in initial milk potential was predicted to increase weaning weight and to decrease calving interval, whereas improvement in persistency was predicted to increase both weaning weight and calving interval. Thus, if selection systems emphasize regular reproduction (as does the Kinsella project), it is likely that cows from a population of the same milk yield will be selected for higher initial milk potential.

If lactation curves of beef cows can be described by a period of rise in milk yield up to a certain peak, and then an exponential decay, the peak point would appear further from calving as the initial milk potential increases. Thus, for beef cows with low **IPDYM** the lactation curve would be characterized by a long decaying curve almost without distinct peaks.

Based on the functions selected for the model from different studies, simulated dry matter intake is likely to increase with an increase in milk production. For cows with large initial milk potential the amount of energy added by the additional intake can supply the requirements of the additional milk which is produced but not used. This may even invoke a surplus of energy in the initial period.

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7. GENERAL SUMMARY AND CONCLUSIONS

7.1 SUMMARY

A deterministic model for simulating beef cattle production under Alberta management schemes and environment, with cows from three genetic groups: Hereford (**HE**), Beef Synthetic (**SY**) and Dairy Synthetic (**DY**) was described. In the model, the genotypes potential (specified as production potential), was reached only if past and present planes of nutrition and climatic conditions were adequate. Intake of pasture or other feeds was simulated as a function of size, maturity and physiological status of the cows in addition to the availability, digestibility and crude fiber content of the feed.

To simulate cow performance, a dynamic set of blocks was used: milk yield, fetal growth, calf growth, energy balance, grazing management, climatic adaptation, body weight and change in reserves. Cow performance was calculated from the interaction among climatic conditions, nutrient intake, animal condition (reserve depot) and genetic potential. Evaluation of the model behavior was made largely by setting climate, grazing and management conditions to those existing at The University of Alberta Ranch at Kinsella, and by validating the simulation output with the observed data.

Three simulated experiments were conducted with the model. In the first, the model was used to study the effect of environmental factors on body weight and composition, feed intake, digestibility, energy balance, level of production and reproduction of range cows in Alberta. Four management options (treatments) were evaluated: 1. improved winter supplementary feeding of 25% crude fiber, 2. controlled temperature of 20°C year round 3. constant feeding program of 28% crude fiber under confinement conditions year round and 4. the same as 3 but with 26% crude fiber. These were compared with a control which was simulated as the actual situation at The University of Alberta Research Ranch at Kinsella.

The second experiment estimated the effect of a severe winter on body weight, feed intake, digestibility, energy balance, level of production and reproduction of range beef cows from the three breeding groups under The University of Alberta Ranch management. The effects of a severe winter were compared with those of a normal winter (as represented by 1976).

In the third experiment, the model was used to study the effect of change in milk potential through change in initial milk yield (**IPDYM**) and persistency (**P**) on body weight, feed intake, milk production, energy balance and level of production and reproduction. Six treatments combining different levels of **IPDYM** with constant levels of **P** and different levels of **P**, with constant levels of **IPDYM** and a combination between the two were compared with a control, which was represented by the actual situation at The University of Alberta Ranch.

7.1.1 Validation

The validation of the model indicated that the concepts introduced were valid and appropriate to biological and productive attributes of a cow-calf system. It was concluded that within the existing limitations, the model was suitable for testing hypotheses concerned with aspects of environmental conditions, milk yield, calf production and biological efficiency.

7.1.2 Evaluation of system behavior

7.1.2.1 Live Weight

The shape of the live weight curve of mature range cows in Alberta was considered as a function of factors such as feed quality, ambient temperature and fetal growth. Energy concentration of the feed was estimated to be the most influential of factors considered in the initial period after calving, and its effect on simulated live weight was predicted to be mainly via the change in empty body weight. Crude fiber in the feed was estimated to be the most influential factor during herbage lignification at the end of the grazing season, and its effect on simulated live weight was predicted to be mainly through the increase in gut fill. Fetal weight was estimated to be a fairly important factor in the last phase of pregnancy (starting three months before calving), and its influence on simulated live weight was predicted to be through the increase in uteral size.

7.1.2.2 Productivity and Reproduction

Increase in feed energy in the winter did not increase simulated 180 day weaning weight, but rather increased the time taken from calving to weaning by shortening the simulated open-days interval.

7.1.3 Evaluation of The Effect of Severe Winter

7.1.3.1 Live Weight

Under the management practices prevailing at The University Ranch, the simulated effect of severe winters on change in weight of beef cows was only a temporary one, and cows were predicted to recover from mid-winter weight loss during the following grazing season.

7.1.3.2 Reproduction

Some reduction in simulated empty body weight was derived from change in reserve tissue which was predicted to recover more slowly. Therefore, fertility may be reduced if cows are not compensated for catabolism of reserve tissue.

7.1.3.3 Energy Metabolism

Simulated maintenance and heat production requirements are likely to increase under severe winters. The increase in maintenance is not always connected directly to the change in temperature, but it is predicted to be dependant fairly strongly on breed and conditions. Hereford cows were predicted to spend relatively more energy on maintenance and less on heat production, whereas **SY** and **DY** were predicted to spend relatively less on maintenance and more on heat production.

Energy balance in cows on limited intake is directly influenced by the increase in maintenance and heat production expenditures. Thus, the more marginal the energy balance is during normal winters, the more severe will be the deficit during a harsh one. Since fat is the tissue in the body which tends to be catabolized under energy deficiency, increases in energy expenditures will cause a reduction in this tissue. Hereford, and **SY** cows were predicted to lose more reserve tissue during severe winters than were **DY** cows.

7.1.4 Evaluation of The Effect of Milk Potential

7.1.4.1 Productivity and Reproduction

Improvement in initial milk potential was predicted to increase weaning weight and to decrease calving interval, whereas improvement in persistency was predicted to increase both weaning weight and calving interval. Thus, if selection systems emphasize regular reproduction (as does the Kinsella project), it is likely that cows from a population of the same milk yield will be selected for higher initial milk potential. Selection as such, is predicted to be preferable over selection for lactation persistency.

7.1.4.2 Lactation Curves

If lactation curves of beef cows can be described by a period of rise in milk yield up to a certain peak, and then an exponential decay, the model predicts that the peak point would appear further from calving as the initial milk potential increases. Thus, for beef cows with low initial potential of milk yield the latation curve would be characterized by a long decaying curve almost without distinct peaks.

7.1.4.3 Dry Matter Intake and Energy Metabolism

Based on the functions selected for the model from different studies, simulated dry matter intake is likely to increase with an increase in milk production. For cows with large initial milk potential the amount of energy added by the additional intake were predicted to supply the requirements and even to invoke a surplus of energy in the initial period.

7.2 CONTRIBUTION AND APPLICATION

One value of simulation is that it requires a modeller to learn about the system intensively and in depth before he can model it successfully. In the course of the construction of this model, the author learned a great deal about biological phenomena in the beef cow cycle. Thus, the contribution of the current modelling and simulation can be summarized as following:

1. The model enables one to understand better the biological processes of beef cattle under specific conditions.
2. Due to the dynamic nature of the model, equations which have been used previously in other cow-calf models (calculated final values) were calibrated to fit to the pattern of seasonal changes.
3. Gaps in existing models of growth and milk production made it necessary to develop hypotheses (Appendix-1,2) dealing with the pattern of growth and milk production of beef cows.
4. Construction of the model enabled precise identification to be made of specific gaps in our knowlage and pointed to further work that needs to be carried out. The most important gap is that not enough is known about herbage intake in a grazing situation. An experiment in which herbage intake, fattening and change in weight will be monitored could help in better understanding of the lipostatic mechanism in relation to the limitation on

increase in body size. Some important gaps have also become apparent in the climate side of the model. Two such gaps are associated with the pattern of the change in body insulation over the seasons and the change in the effect of more climatic parameters than temperature.

5. The model documented the evironmental stress experience by breeding cows in Alberta. There is a gap between voluntary intake and maintenance requirements while on pasture, and there are important interactions with season and physiological state of the animal. This information is of value in studying the problem of nutritional stress and in evaluating strategies for supplying the deficient nutrients.
6. Most beef production models reported in the literature are models of improved systems with animals kept under thermoneutral conditions. Such models are of limited use in very cold areas when the task is to find economically feasible and relatively extensive husbandry systems. The model developed in this research allows simulation of cows performance under conditions of cold stress.
7. The model can also be used as a tool to make quick estimations of supplementary feed requirements as conditions change.

By interpreting the individual conclusions as described in the summary section, the following applications were defined:

1. Since pasture availability was predicted by the model to

have a very important role in affecting calf growth (mainly in final stages before weaning), it is evident that changing the grazing management system or using supplementary feeding in the final stages is expected to improve calf growth under Alberta conditions.

2. It was estimated by the model that a diet high in fiber can not satisfy production requirements of the lines of cattle which have been developed at The University of Alberta Ranch. Therefore, a confinement program based on such a diet is not recommended.
3. It is expected based on the predictions of the model that selection for fertility (which is considered to be a poor trait for a selection program, but is practiced at The University Ranch for practical reasons) can induce selection gain in milk yield and feed intake.
4. Based on the model's predictions, it is assumed that milk production is more important in initial stages (despite the fact that the calf can not use the total amount of the milk) than in the terminal stages (at which time milk yield is susceptible to changes in pasture quality). Therefore it is recommended that selection programs give greater weight to early lactation yield.

7.3 FURTHER RESEARCH

During the course of model development and evaluation, several aspects of environmental and physiological functions requiring further research were identified, based on inadequacies in available data or in model performance. The following problems were identified as requiring additional consideration:

1. The lipostatic mechanism is not sufficiently sensitive to the combined effect of feed intake and body size.
2. Due to lack of good quantitative data on the dry matter intake and digestibility on pasture, the prediction of the model could not be validated.
3. More information is needed on parameters of weather and climate, and on the physiological, morphological and behavioral responses of cattle to meteorological changes.
4. The grazing sub-model is not sufficiently dynamic. It does not respond to changes in weather or grazing pressure.
5. No data was found on the relationship between the value of residual milk during early lactation, and feed intake and fattening in the cow.
6. Similarly, there is a lack of information on the relationship of fertility to milk yield during early and late lactation.

The following stages of development are suggested for the future:

1. The model should be validated using additional experimental data.
2. Specifically, the model should be tested for sensitivity to changes in feed quality and ambient temperature.
3. An economic analysis factor should be added to the model.
4. The model should be adapted to a farm situation, and applied to the analysis of management systems.
5. Depending on its final accuracy, the model should be used for decision making. Among the management problems to which the model is oriented, the most urgent are choice of supplementary feeding plan and choice of weaning weight and time.

If these applications prove successful, it will be possible to develop a control system for management, with a variable or uncertain productive capacity.

Finally, the model could have application in other fields, such as introduction of feed utilization criteria into the breeding scheme, and improving the resolution of analysis of experiments.

APPENDICES

Appendix-1

A modified growth model for beef cows in Alberta

Abstract

A modified growth model for beef cattle has been developed. By using analytical techniques,the mathematical functions to fit the growth model have been derived. Brody's model (Brody, 1945) recognizes two stages in the growth pattern of a cow: pre-inflection and post-inflection growth. Age-weight data of beef cattle from The University of Alberta Ranch at Kinsella consisting of 203 Beef Synthetic (SY) and 144 Hereford (HE) females (set 1) were used for the computation of model parameters, degree of maturity at birth and at inflection point (Table A.1.1). The mean value for degree of maturity at birth was 6.8% and the mean inflection point was 36% of mature weight (Rosen and Berg, 1981). For the validation of the model, another set (set 2) of 23 females of all breeding groups (HE, SY and Dairy Synthetic (DY)) were used. Polynomial and nonlinear regression analysis of age-weight data were computed to yield least squares (LS) curves for comparison. The performance of the model was tested in three ways: (a) A graph comparing the values of the model with the LS curves and the observed data (Figures A.1.1 to A.1.5), (b) the coefficients of variation (CV) of forecast deviations were calculated as percentage of the mean of the observed data, and (c) correlation forecast (r^2)(i.e. correlation between model LS and the observed

curve) (Tables A.1.2 and A.1.3). The overall **CV** of the simulated curves was found to be 17.00±5.3% and the r^2 0.958±0.0051. To increase the degree of fit with the observed data, multiplicative correction factors of **k** for suboptimal conditions were estimated (a computer program which changes k and checks for the minimal residual variance was used to calculate a new k. The new k was then compared with the k which was estimated by the model) as : 1.4 for **HE** and **SY**; and 1.8 for **DY**. The actual growth of **DY** was the only one which required adjustments for **A** ((1.08) which makes it 0.74 for the average **DY** cow) as well as **k**. The overall CV for the adjusted simulated curves was 9.56±0.31%. The adjusted growth curves are presented in Table A.1.4 and Figures A.1.6. to A.1.8.

Tables

Table A.1.1 The evaluation of degree of maturity at birth.

	Model					
Breeding Group	Richards (1-B)	*Corrected MPE	(1-B)	Brody (1-B)	*Corrected MPE	(1-B)
SY	0.064	1.0070	0.0644	0.078	0.8710	0.068
SY	0.069	0.9855	0.0680	0.068	1.0010	0.068
HE	0.065	1.0165	0.0660	0.072	0.9452	0.068
HE	0.071	1.0034	0.0712	0.062	1.1066	0.068
Overall Mean			0.0674			0.068

MPE-Mean Predicted Error=(Observed-Predicted)/Observed

(1-B)-degree of maturity at birth.

Brody's equation- $\text{Weight}=A(1-Be^{-kt})^{1}$

Richards' equation- $\text{Weight}=A(1-Be^{-kt})^{m}$

*corrected back to the observed value.

A-mature weight.

k-rate of maturity.

t-time.

Table A.1.2 The coefficient of correlation and of variation for age-weight data (set 1) of two prediction models and of an estimation model in two breeding groups of cattle.

			Model					
Breeding	No.		Estimation		Polynomial LS		Nonlinear LS	
Group	A.	O.	r^2	CV(%)	r^2	CV(%)	r^2	CV(%)
HE	144	9	0.9705	7.137	0.9705	4.775	0.9783	6.486
SY	203	9	0.9544	8.518	0.9863	4.991	0.9741	6.950

A.-number of animals

O.-number of obsevations within animal

Polynomial model- $\text{Weight}=b_0+b_1t+b_2t^2$

Nonlinear model- $\text{Weight}=A(1-e^{-kt})$- used in the estimation model to predict mature weight based on estimated A and k for each group.

Table A.1.3 The coeficient of correlation and of variation for age-weight data (set 2) of two prediction models and of an estimation model in three breeding groups of cattle.

			Model					
Breeding Group	No.		Estimation		Polynomial LS		Nonlinear LS	
	A.	O.	r^2	CV(%)	r^2	CV(%)	r^2	CV(%)
HE	5	47	0.938	14.58	0.933	9.72	0.946	8.75
SY	9	47	0.945	13.28	0.934	9.20	0.946	8.27
DY	9	47	0.935	23.16	0.919	9.78	0.936	8.63

A.-number of animals

O.-number of observations within animal

Table A.1.4 Mature weight (A) and rate of maturity (k) of the nonlinear fitted model, the theoretical estimation model and the adjusted estimation model in three breeding groups of cattle.

Breeding Group	Model								
	Nonlinear Predicted			Estimation model			Estimation adjusted		
	A	k(%)	CV(%)	A	k(%)	CV(%)	A	k(%)	CV(%)
HE	502.6	0.173	8.75	517.6	0.234	14.58	517.6	0.167	9.34
SY	525.5	0.173	8.27	536.7	0.279	13.28	536.7	0.199	8.41
DY	472.5	0.230	8.63	550.0	0.283	23.16	505.4	0.117	8.71

Graphs

FIGURE A.1.1.

GROWTH CURVES OF HEREFORD COWS
SET-1

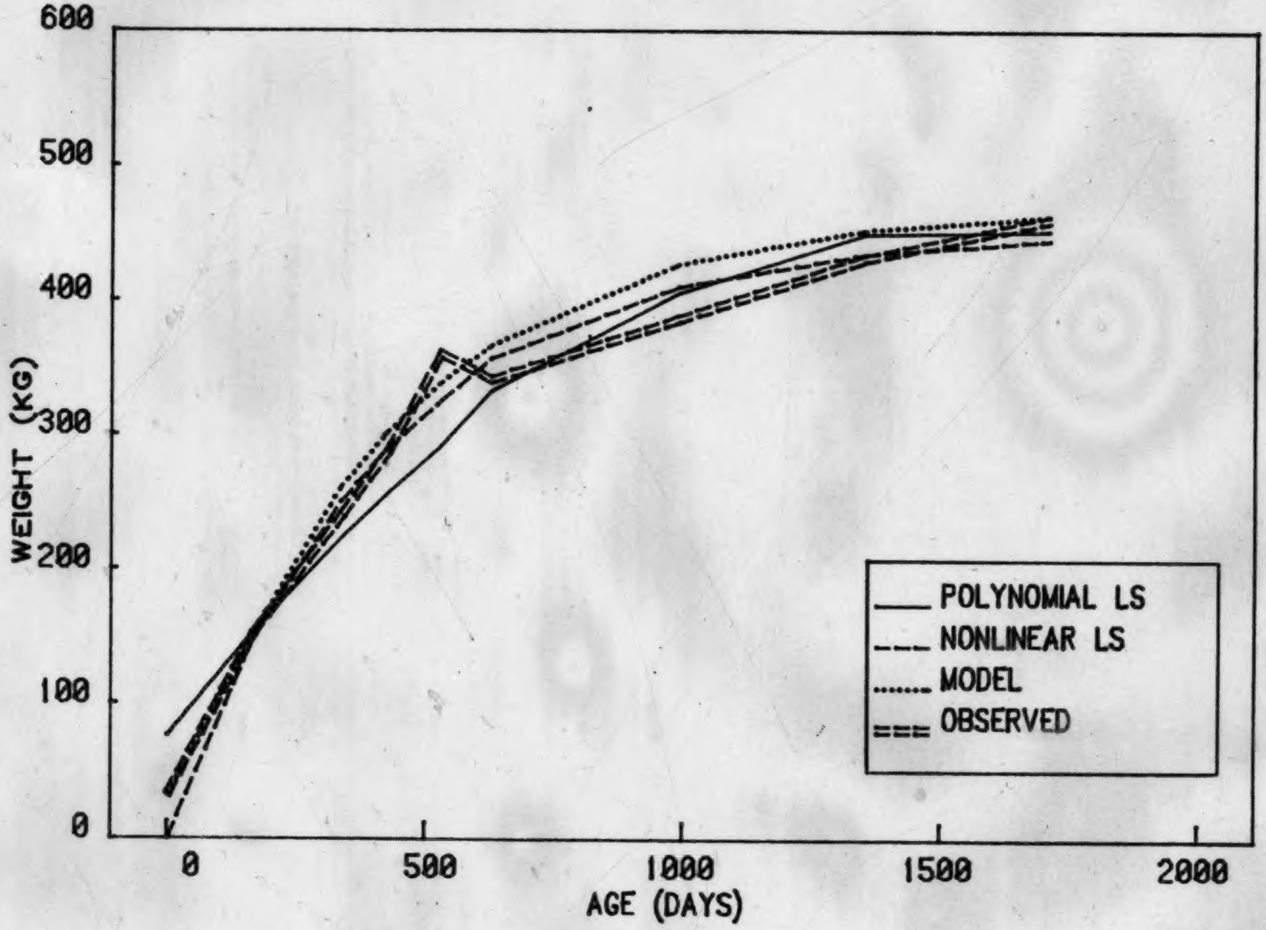


FIGURE A.1.2.

GROWTH CURVES OF BEEF SYNTHETIC COWS
SET-1

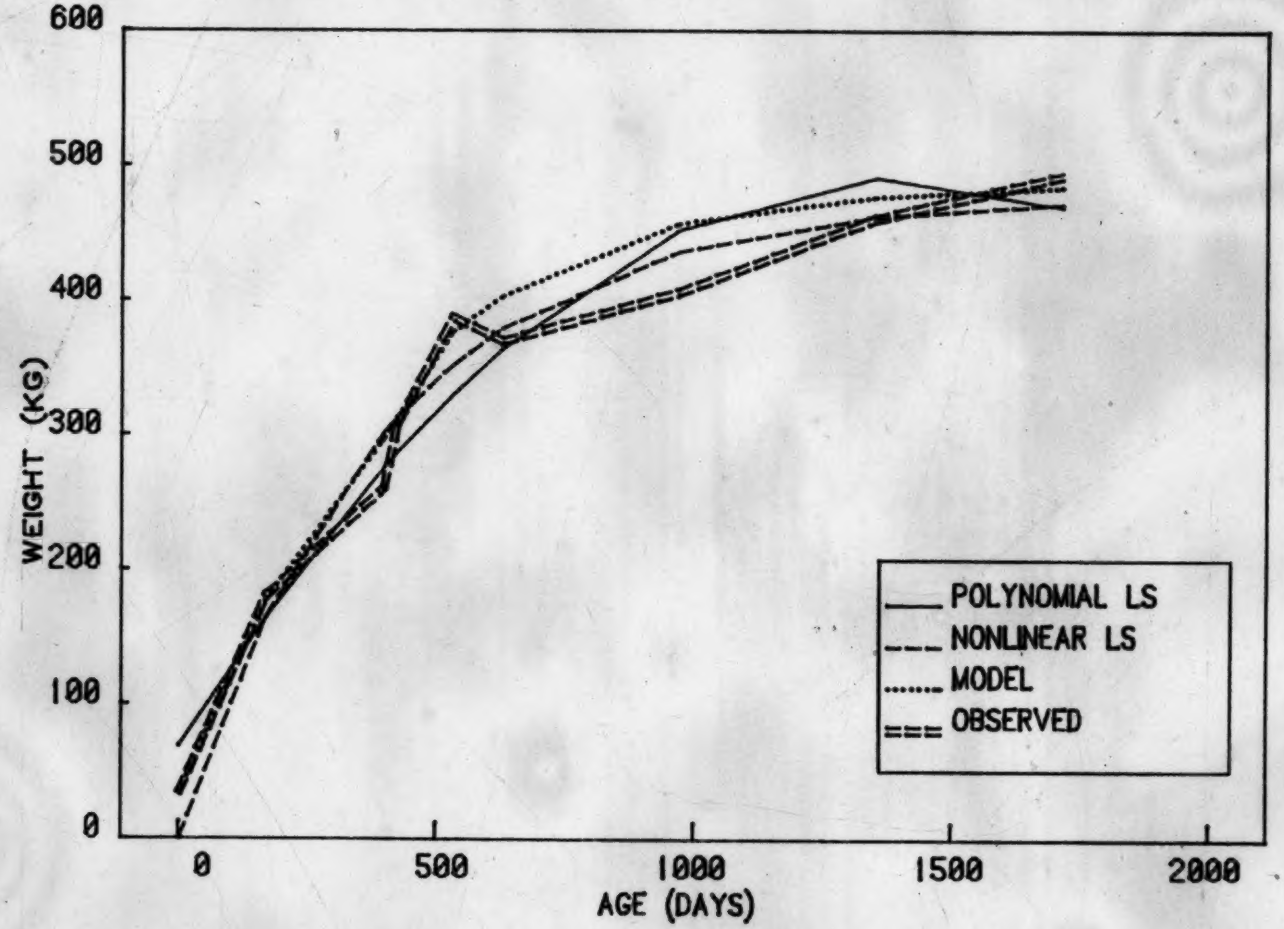


FIGURE A.1.3.

GROWTH CURVES OF HEREFORD COWS
SET-2

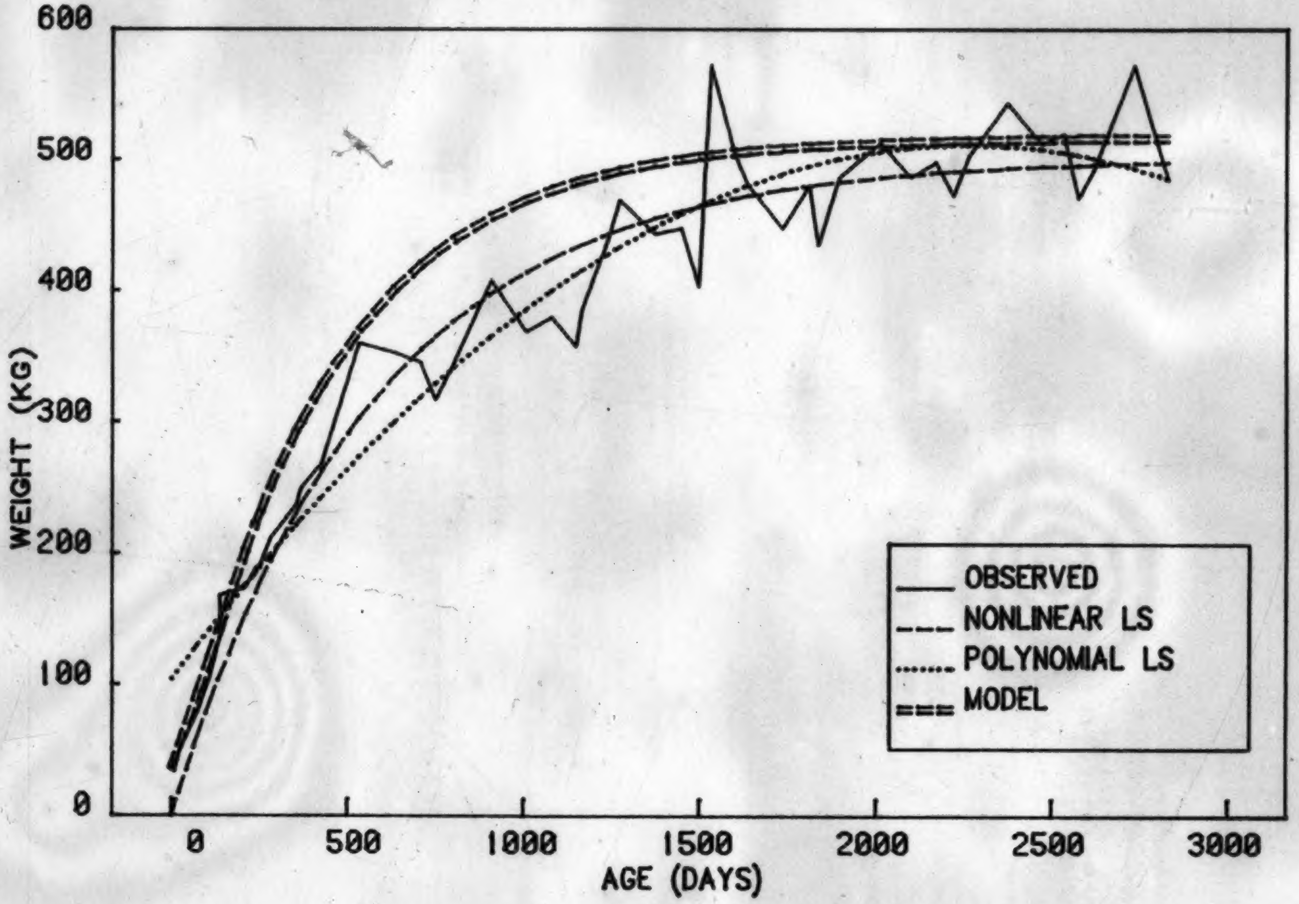


FIGURE A.1.4.

GROWTH CURVES OF BEEF SYNTHETIC COWS
SET-2

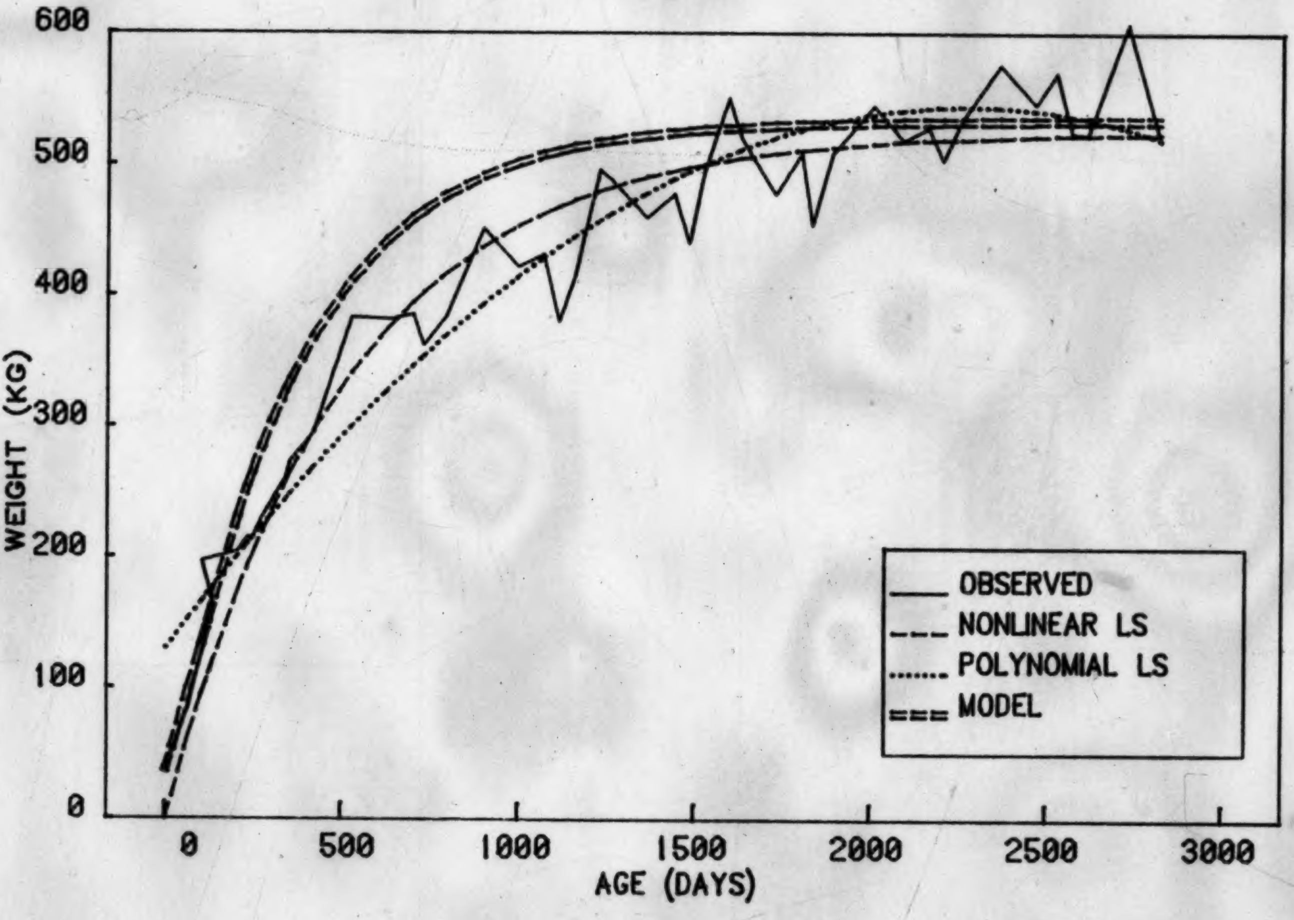


FIGURE A.1.5.

GROWTH CURVES OF DAIRY SYNTHETIC COWS
SET-2

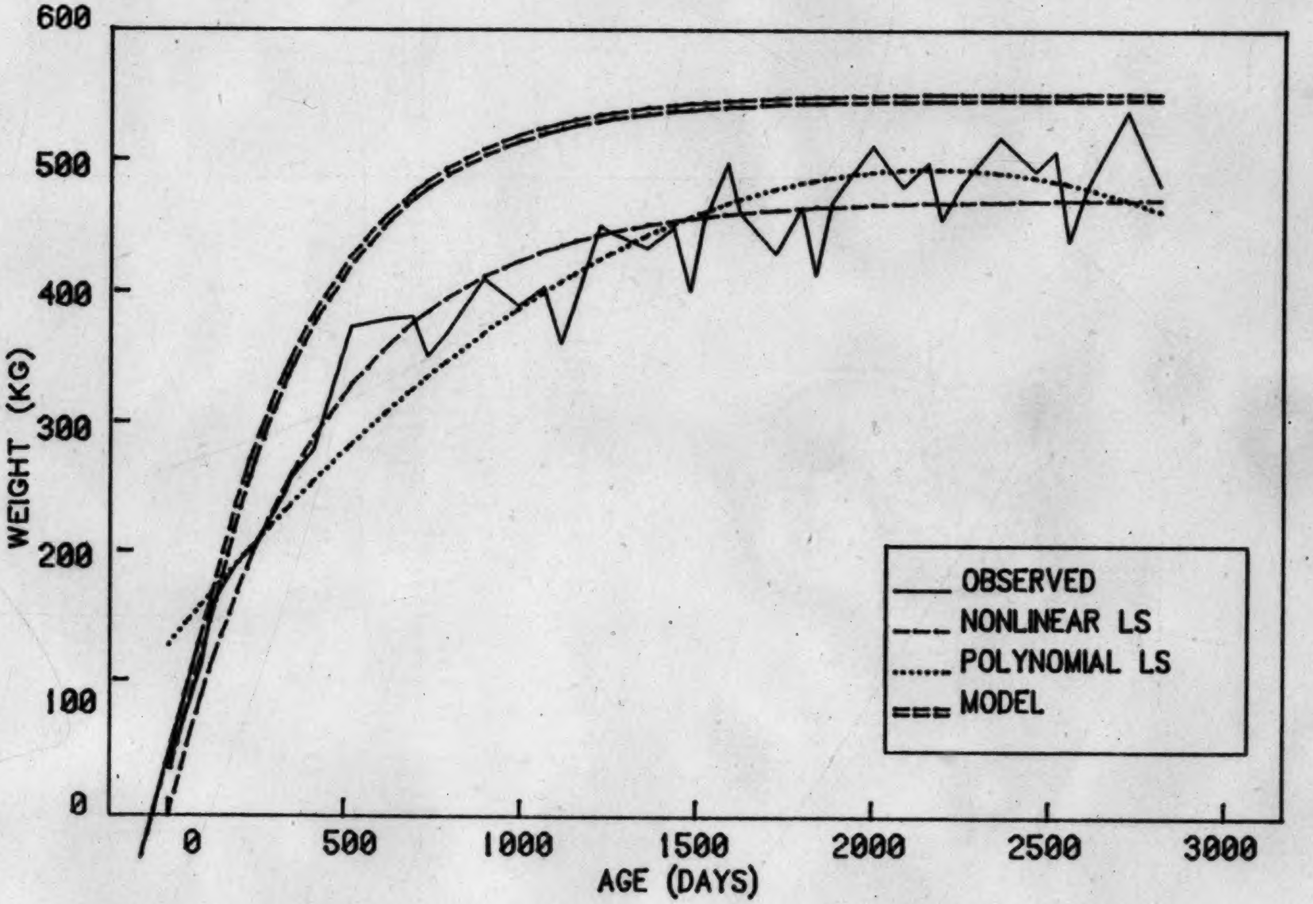


FIGURE A.1.6.

GROWTH CURVES OF HEREFORD COWS

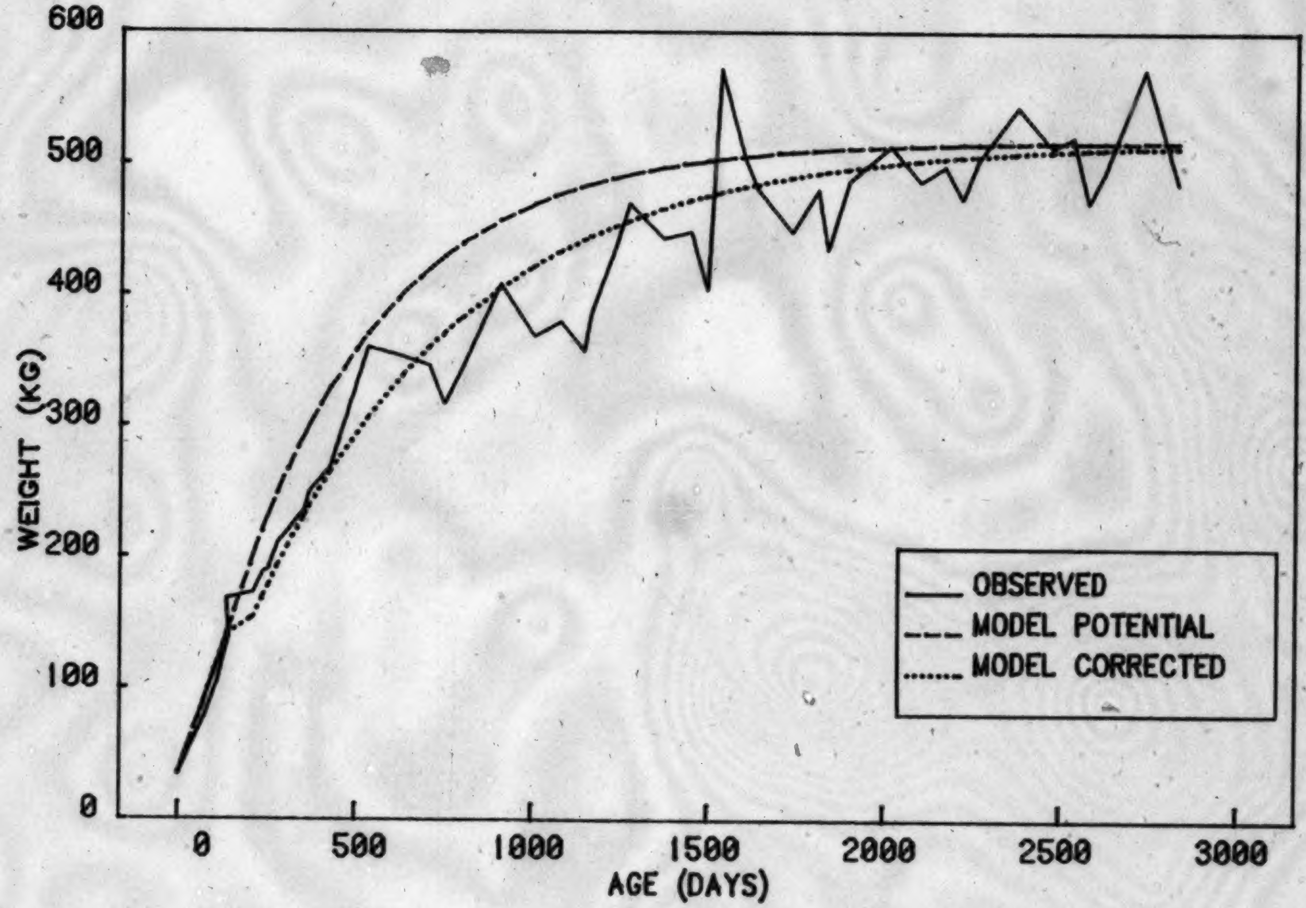


FIGURE A.1.7.

GROWTH CURVES OF BEEF SYNTHETIC COWS

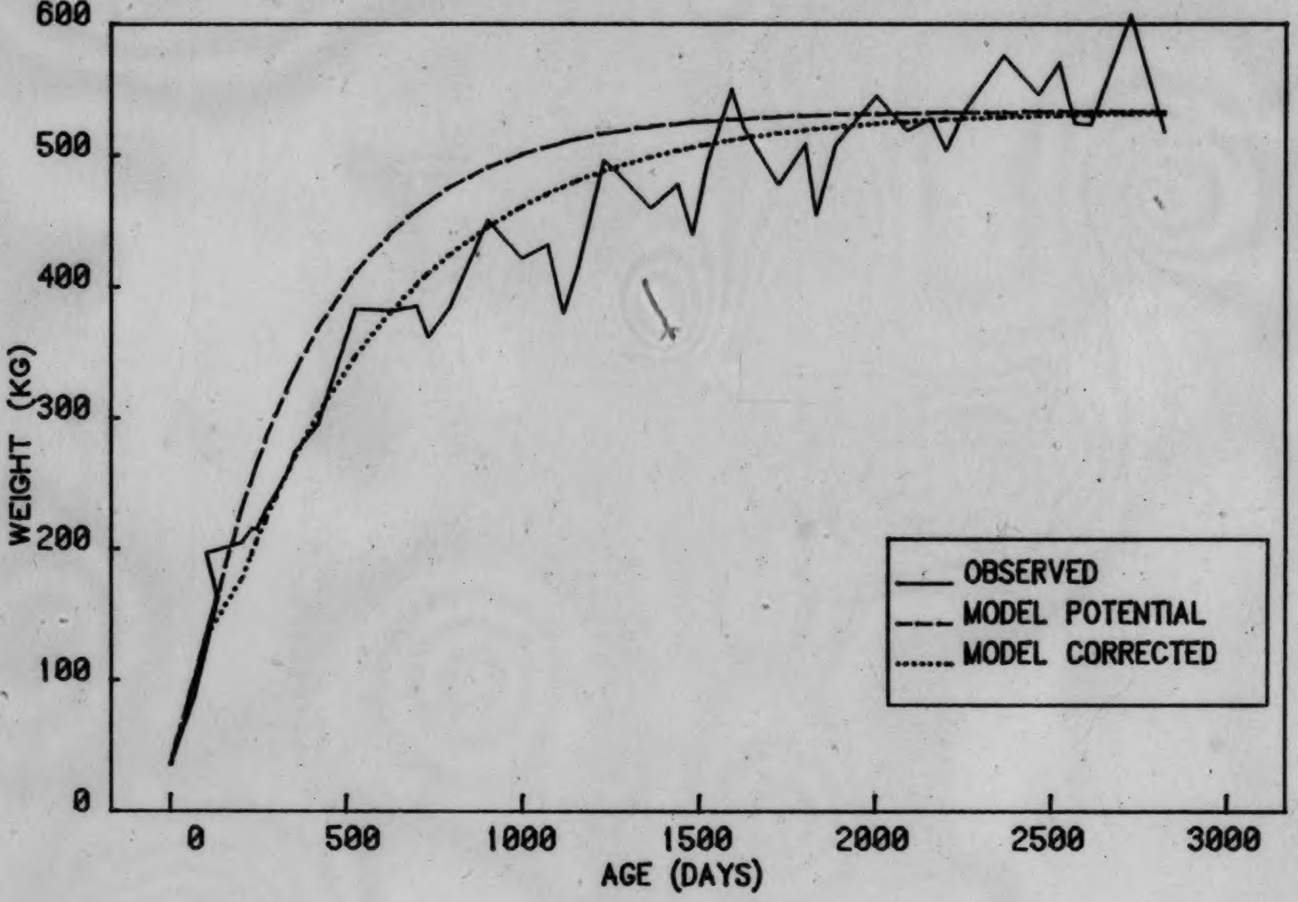
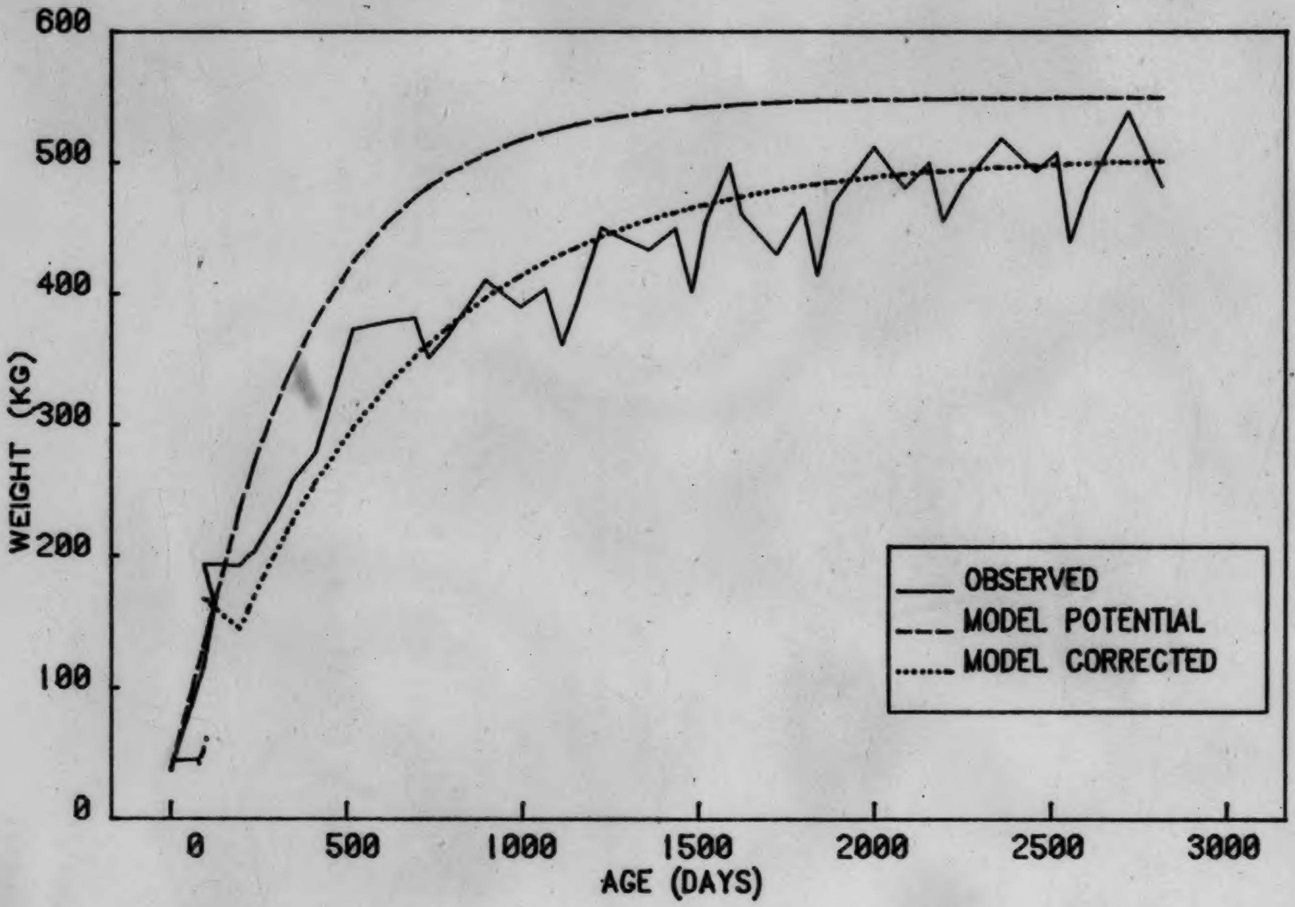


FIGURE A.1.8.

GROWTH CURVES OF DAIRY SYNTHETIC COWS



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Rosen, M. and Berg, R.T. 1981. A new approach in beef cattle growth pattern analysis. Can. J. Anim. Sci. 61:1083 (Abs).

Appendix-2

Relationship between milk production and preweaning growth of calves in three lines of beef cattle in Alberta

Abstract

A milking experiment with single-suckled range beef cows, which was conducted over two lactation years (1976 and 1977) at The University of Alberta Ranch at Kinsella (Butson, 1981), was used for the analysis of lactation curve parameters. Initial daily milk yield and lactation persistency were analyzed using least squares techniques (Table A.2.1 and Figure A.2.1). Breeding group had a significant effect on initial milk yield, whereas age of dam had a significant effect on persistency of lactation, and year had a significant effect on both parameters (Table A.2.2). Multiplicative correction factors of age of dam for total predicted milk yield were computed also, and found to be: 1.35, 1.19, 1.05 and 1.00 for cows aged 2 to 5+ years. A milk production model was programmed, and the relationship between calf growth and milk production was simulated. Using simple regression analysis the relationships between simulated growth on milk and observed growth were analyzed. These relationships on a calf weight basis were found to have a better predictive ability than those on a calf gain basis (Figures A.2.2 and A.2.3). Calf growth efficiency with respect to milk consumption was simulated, and breeding group differences were found (Table A.2.3 and Figure A.2.4).

Hereford and DY calves were predicted to be more efficient in utilizing pasture in the early period, whereas SY calves were more efficient in utilizing pasture in the later period.

Tables

Table A.2.1 Least squares means, standard errors and multiplicative correction factors of IPDYM, P and June and September daily milk yield in three breeding groups of cattle.

Item	Number of Animals	P	IPDYM Kg/Day	Milk Yield **	
				June	September
Breeding Group					
HE	103	0.151±0.010	9.26±0.5	7.02±0.4	4.46±0.3
SY	225	0.120±0.008	10.25±0.3	7.92±0.3	5.86±0.3
DY	61	0.094±0.015	10.47±0.6	8.65±0.5	8.65±0.5
Multiplicative Correction Factors of Milk Yield *					
Age of Dam					
2	137	0.90	1.26		
3	88	0.92	1.12		
4	46	1.12	1.12		
Mature	157	1.00	1.00		
Sex					
Male	205	1.00	1.00		
Female	223	1.11	1.07		

* Additional breeding group of 39 cows is included in the data.
** Adopted from Butson (1981).

Table A.2.2 Analysis of variance of initial daily milk yield and persistency of lactation in three breeding groups of cattle.

Source	Degrees of Freedom	Mean Squares (IPDYM)	Mean Squares (P)
Breeding Group	2	27.5	0.792*
Sex	1	11.3	0.058
Age of Dam	3	132.9*	0.102
Year	1	262.6*	1.669*
Error	419	19.9	0.143
Total	428		

* $P<0.01$

Table A.2.3 Estimated average milk utilization efficiency expressed in kg milk per kg preweaning gain for the periods ending on the 80th, 150th, 180th and 200th day, in three breeding groups of cattle.

Breeding Group	Days from Calving			
	80	150	180	200
	kg milk/kg gain			
HE	7.90	7.21	7.34	7.54
SY	8.42	7.25	7.32	7.54
DY	8.07	7.22	7.32	7.55

Graphs

FIGURE A.2.1.

LACTATION CURVES OF THE THREE LINES CALCULATED BASED ON IPDYM AND P

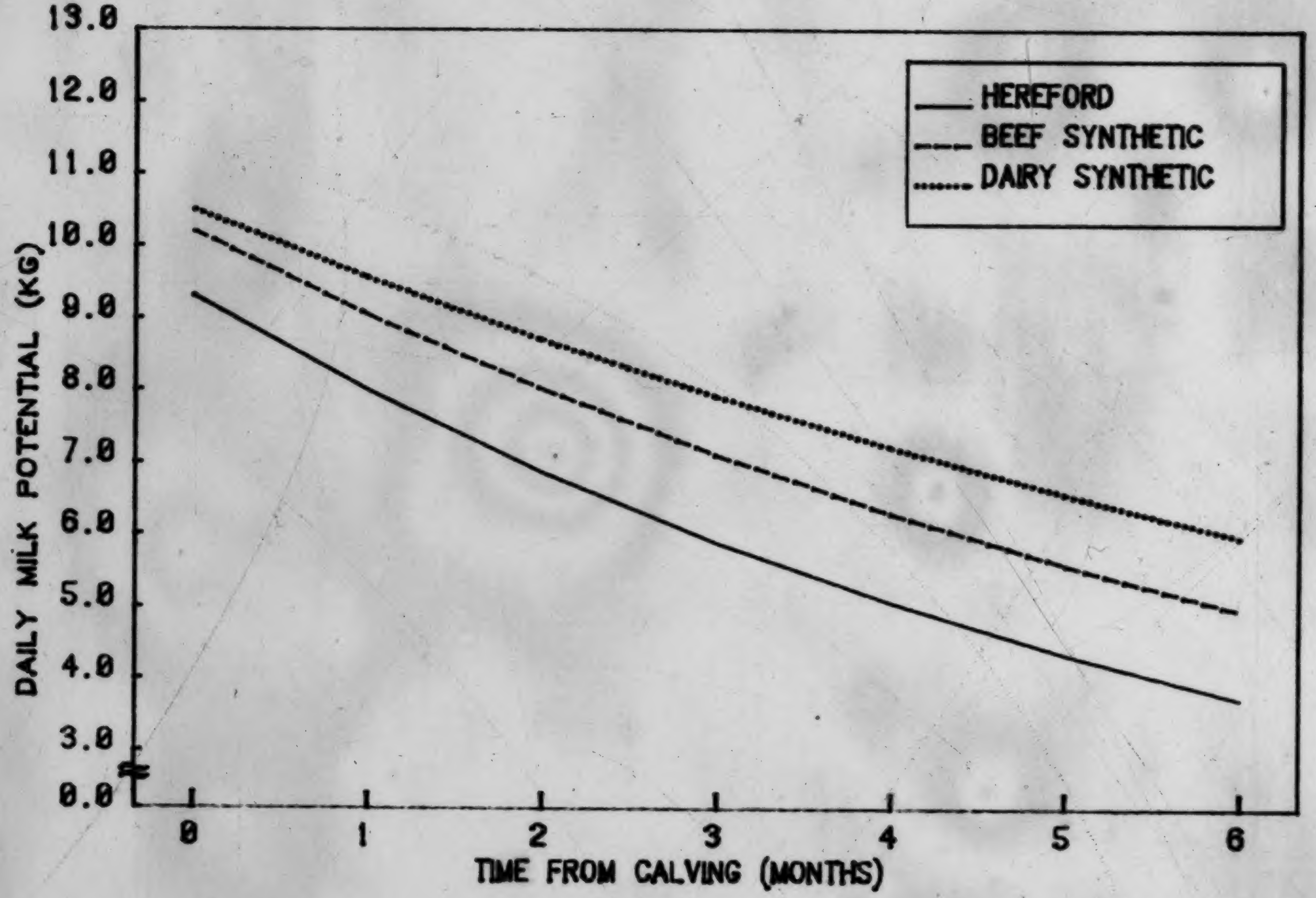


FIGURE A.2.2.

PROPORTION OF CALF DAILY GAIN TO SIMULATED DAILY GAIN FROM MILK

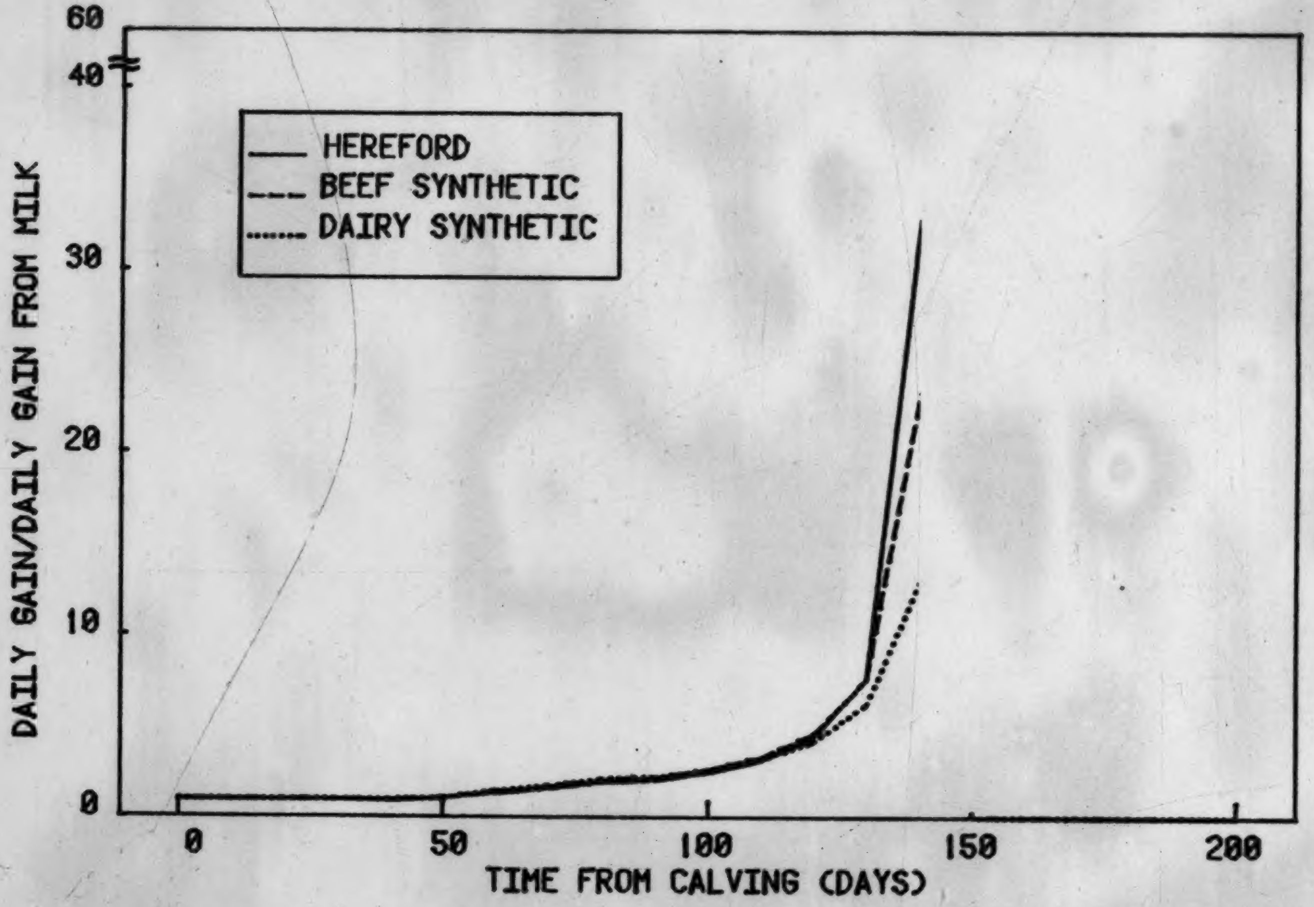


FIGURE A.2.3.

PROPORTION OF CALF TOTAL WEIGHT TO SIMULATED WEIGHT FROM MILK

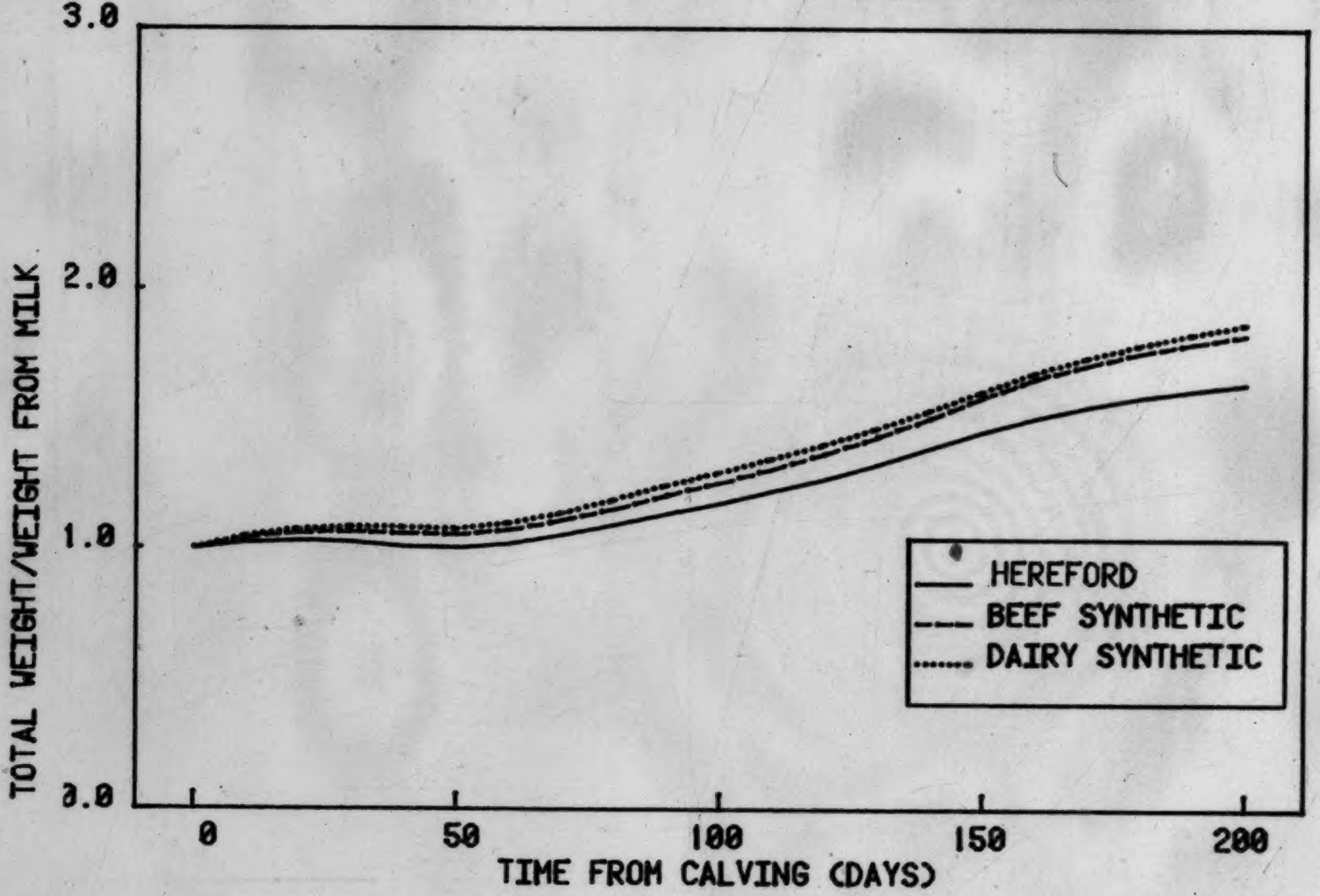
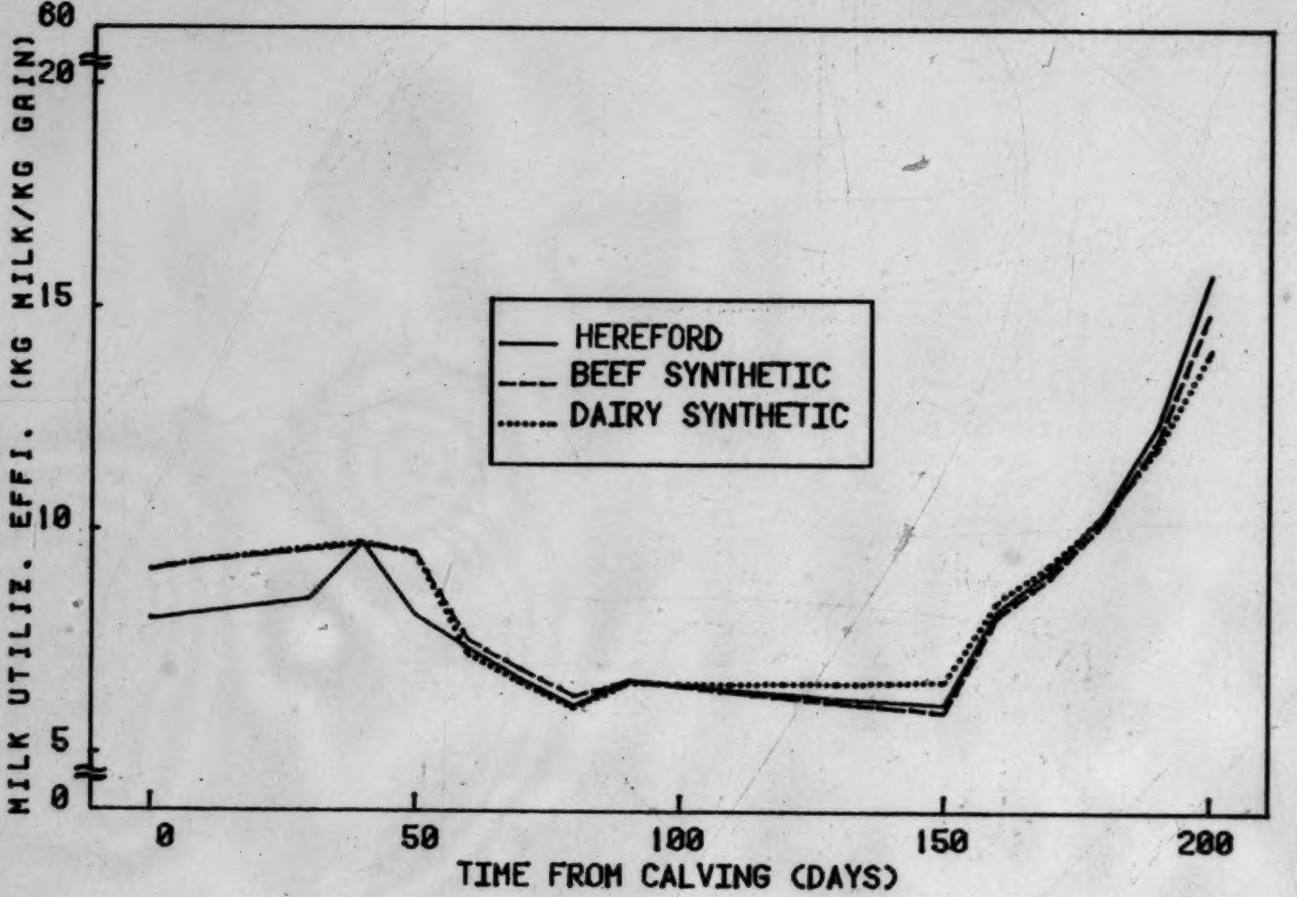


FIGURE A.2.4.

MILK UTILIZATION EFFICIENCY IN THREE LINES OF CATTLE



Reference

Butson, S.L. 1981. Biostatistical analyses of factors influencing lactation performance of range cows and weaning weight of their calves. M.Sc. Thesis. Dept. of Animal Science, Univeristy of Alberta, Edmonton, Alberta.

Appendix-3

Least squares analysis of calving intervals and calving season

Least squares analysis of calving interval and time taken to mid-season in three breeding groups of cattle and four classes of age group.

Item		Calving Interval		Mid-Season Interval		
		Cow	Heifer	Cow		Heifer
				Normal	Adjusted*	
		(days)			(days)	
Breeding Group						
HE	No.	515	358	1321	515	358
	Mean±S.E.	369.6±0.9	732.0±1.2	33.9±0.7	31.1±0.6	27.0±0.9
SY	No.	996	602	2259	996	602
	Mean±S.E.	368.6±0.8	730.7±0.9	30.0±0.5	29.8±0.5	23.5±0.7
DY	No.	172	97	345	172	97
	Mean±S.E.	370.5±1.6	726.8±2.2	32.6±0.6	31.3±1.0	23.9±1.6
Age of Dam						
3	No.	601		782	601	
	Mean±S.E.	374.3±0.1		32.9±0.8	29.7±0.5	
4	No.	385		616	385	
	Mean±S.E.	369.3±1.2		34.1±0.9	33.4±0.7	
5+	No.	697		1619	697	
	Mean±S.E.	365.0±1.0		29.6±0.8	31.1±0.6	
Sex						
M	No.	865	528	1938	865	528
	Mean±S.E.	369.9±0.9	730.6±1.2	33.0±0.7	32.0±0.5	24.9±0.9
F	No.	818	529	1987	818	528
	Mean±S.E.	369.1±0.8	729.1±1.2	31.3±0.7	30.9±0.5	24.8±0.7
Overall						
	NO.	1683	1057	3925	1683	1057
	Mean±S.E.	369.5±0.8	729.9±1.0	32.2±0.6	31.4±0.5	24.8±0.7

*-adjusted for calving interval.

Appendix-4

Regression analysis of weaning weight and age on number of days of low temperatures (-18°C and lower) in the winter

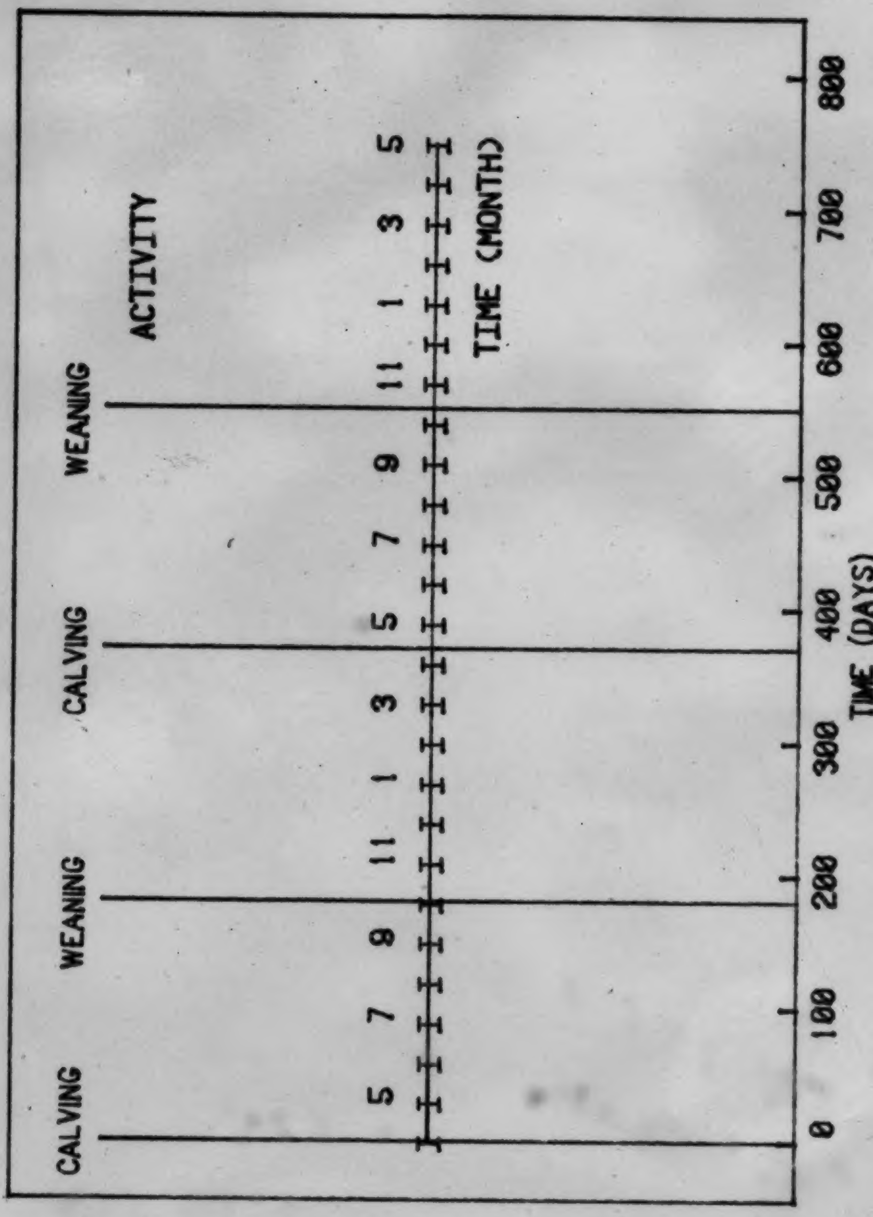
Mean and standard deviation (SD) for dependent variables-(*). R^2, intercept and standard error (SE) of estimate and regression coefficients (B) from simple regression analysis to estimate weaning weight and weaning age of calves from three lines of cattle in Alberta (based on data from Berg (1975) as explained in chapter 5)

	Dependent		Estimates			
Breeding Group	Mean	SD	Intercept	B	SE	R^2
1 Weight (kg)						
HE	157.6	6.02	170.7	-0.1349	0.110	0.2720
SY	192.8	5.35	212.9	-0.2084	0.048	0.8250
DY	205.0	9.59	227.7	-0.2355	0.169	0.3271
2 Age (days)						
HE	159.3	7.50	155.4	0.0409	0.159	0.0161
SY	162.3	5.89	162.3	0.0000	0.126	0.0000
DY	159.0	7.01	149.4	0.0995	0.142	0.1092

* weaning weight and age.

Appendix-5.1

A detailed timing index for the graphs



Appendix-5.2

Glossary

NOTE: Variables which appear in the program but not in this list are used only for intermediate calculations.

A -	mature weight, kg.
AFTPR-	abdominal fat, kg.
ADG -	average daily gain, kg/day.
AGE -	age of cow, years.
AI -	initial value of DEF, kg/day.
ANIDP-	stocking rate, cows/acre/year.
ANOVA-	analysis of variance.
AVI -	pasture availability, fraction.
B -	growth scaling parameter, dimensionless.
BM -	energy for maintenance adjusted for TEMP, Mcal/day.
BT -	biological type corrected factor for VFI, dimensionless.
BTIME-	open days interval, days.
BULL -	bulls fertility, fraction.
BWI -	initial body weight, kg.
BWT -	cow birth weight, kg.
CAWT -	calf preweaning milk gain, kg.
CAWTX-	calf preweaning actual gain, kg.
CBWT -	calf birth weight, kg.
CDDMIP-	calf dry matter intake, kg/day.
CDEM -	energy density in feed for calf,

Mcal/kg.DM.

CDIG -	digestibility for calf, fraction.
CF -	crude fiber in feed, %.
CFFTPR -	correction factor for butterfat in milk, dimensionless.
CFFGN-	fat free in calf gain, %.
CFP -	crude fiber in pasture, %.
CFTGN-	fat in calf gain, %.
CKF -	metabolizable energy utilization for growth in calf, fraction.
CKM -	metabolizable energy utilization for maintenance in calf, fraction.
CMEGR-	calf ME for growth, Mcal/day.
CMEM -	calf ME for maintenance, Mcal/day.
CMIC -	calf liquid milk capacity, kg/day.
CNER -	calf net energy retention, Mcal/day.
COND -	cow conditions, dimensionless.
CV -	coefficient of variation, %.
CVDATE-	calving date, days.
CVFIT-	calf VFI adjusted for TEMP, kg/day.
CVGN -	caloric value of gain, Mcal/kg.
CVTIME-	calving time, days.
CWPOR-	the proportion between calf actual growth and milk growth, fraction.
CWT -	calf simulated weight from milk, kg.
CWTX -	calf simulated actual weight, kg.
DAYS -	number of days in each month, days.

DDELAY-	delay time for simulated cow age, days.
DDMIP-	dry matter removed from pasture, kg/acre/day.
DDMP -	dry matter added to the pasture biomass (growth), kg/acre/day.
DEF -	milk loss due to past effect, kg/day.
DELAY1-	delay pasture time, days.
DIG -	digestibility, fraction.
DMAP -	dry matter available from pasture, kg/day.
DME -	the ME density in feed for cows, Mcal/kg.
DMIN -	dry matter intake, kg/day.
DMIP -	pasture removed by cow and calf, kg/cow/day.
DMPP -	pasture residual, kg/acre/day.
DMPP1-	pasture biomass growth, kg/acre/day.
DOM -	degree of maturity, fraction.
DOMB -	degree of maturity at birth, fraction of mature weight.
DY -	Dairy Synthetic.
DYM -	daily yield of milk, kg/day.
EBD -	energy from body tissue, Mcal/day.
EBGN -	empty body gain, kg/day.
EBW -	empty body weight, kg.
EBW1 -	initial empty body weight, kg.
EDIF -	input-output energy difference,

	Mcal/day.
EDM -	energy demand, Mcal/day.
EFD -	energy in the feed, Mcal/day.
EFT -	energy in fetus, Mcal/day.
EGAIN-	energy in weight gain, Mcal/day.
ELOSS-	energy in weight loss, Mcal/day.
EM -	energy in milk, Mcal/day.
EMH -	energy for keeping body temperature under cold stress, Mcal/day.
FACD -	correction factor for physical limitation on VFI, dimensionless.
FACP -	correction factor for physiological limitation on VFI, dimensionless.
FCM -	fat corrected milk, kg/day.
FERT -	cow fertility, accumulated fraction of calvings.
FERTIL-	cow herd fertility, accumulated fraction of calvings.
FRE -	energy retention in fetus, Mcal/day.
FWT -	fetal weight, kg.
GAIN -	calf preweaning daily gain, kg/day.
GAIN1-	calf simulated preweaning gain from milk, kg/day.
GAIN2-	calf simulated preweaning actual gain, kg/day.
GL -	gestation length, days.
GN -	daily gain, kg/day.

GR - grain in diet, %.

----------------regression factors for adjusting actual-milk growth.

GRP0 - intercept.

GRP1 - regression coefficient.

GRP2 - exponent.

---.

GSTIM- gestation time, days.

G2 - empty body weight factor, fraction.

HE - Hereford

HQ - the begining of the grazing season, days.

HRA - grazing time, days.

IE - external insulation, °C.m^2.d./Mcal.

IPDYM- initial potential daily yield of milk, kg/day.

ITT - tissue insulation, °C.m^2./Mcal.

IVFILC- a VFI correction factor, dimensionless.

K - rate of maturity, dimensionless.

KF - a ME utilization efficiency for fattening, fraction.

KL - a ME utilization efficiency for lactation, fraction.

KM - a ME utilization efficiency for maintenance, fraction.

KP - a ME utilization efficiency for pregnancy (fetal growth), fraction.

LACTID-	lactation time, days.
LACTIM-	lactation time, months.
LACTIN-	the time where GAIN > GAIN1 at first, days.
LI -	number of maintenance levels, dimensionless.
LIP -	lipostatic coefficient, dimensionless.
LIPOS-	lipostatic correction factor, fraction.
LS -	least squares.
LWT -	live weight potential, kg.
MCLV -	milk caloric value, Mcal/kg.
M -	weight exponent constant, dimensionless.
ME -	metabolizable energy, Mcal.
MEM -	energy for maintenance, Mcal/day.
MFTPR-	milk fat percentage, %.
MGCF -	growth multiplicative correction factor, dimensionless.
MLKEF-	milk utilization efficiency, kg milk (or FCM)/kg gain.
MMECF-	milk ME value for calf, Mcal/day.
MONTH-	calendar month, Months.
MRE -	retention energy in milk, Mcal/day.
P -	lactation persistency, dimensionless.
PDMIN-	potential dry matter intake, kg/day.
PDRU -	potential of reserve utilization, Mcal/day.
PDYM -	potential daily milk yield, kg/day.

PDYM1-	unadjusted potential milk yield, kg/day.
PDYM2-	potential milk yield adjusted for past effect, kg/day.
PGN -	potential daily gain, kg/day.
PIGN -	preinflection gain, kg/day.
PLWT -	potential live weight, kg.
POI -	point of inflection.
r^2 -	coefficient of corelation.
RDIG -	reduction in digestibility, fraction.
RDYM -	reduction in daily milk yield due to energy deficiency, kg/day.
RES -	reserve tissue, Mcal.
RESCH-	rate of change in reserve, Mcal/day.
RESAVE-	reserve tissue componenet, fraction of EBW.
RESI -	initial RES, Mcal.
RES2 -	reserve tisuue weight, kg.
RVFIF-	a VFI correction factor for abdominal fat, dimensionless.
RVFIP-	a VFI correction factor for uteral space, dimensionless.
SA -	body surface, m^2.
SE -	standard error.
SU -	supplementation feeding, kg/day.
TBOUT-	time to pull bulls out, days.
TBULL-	time to put bulls in, days.
TC -	lower critical temperature, °C.

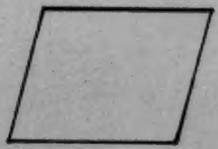
TEMP -	ambient temperature, °C.
TTBULL-	breeding season time, days.
VDMIP-	potential VFI, kg/acre/day.
VFI -	voluntary feed intake, kg/day.
VFID -	physical VFI, kg/day.
VFIP -	physiological VFI, kg/day.
WCOW -	cow live weight, kg.
WCOWI-	cow initial live weight, kg.
WCOWX-	cow experimental live weight, kg.
WETIM-	weaning time, days.
WSPD -	wind speed, km/hr.

Appendix-6

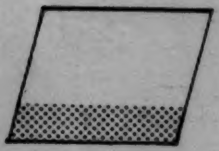
Computer Flow Charts and Programs

Symbols related to the flowcharting

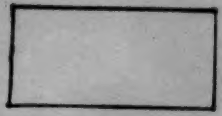
NOTE: Output of one subprogram is used as an input in another subprogram



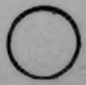
Input



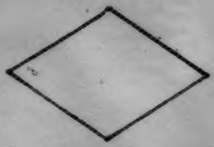
Output



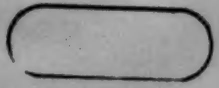
Intermediate variables



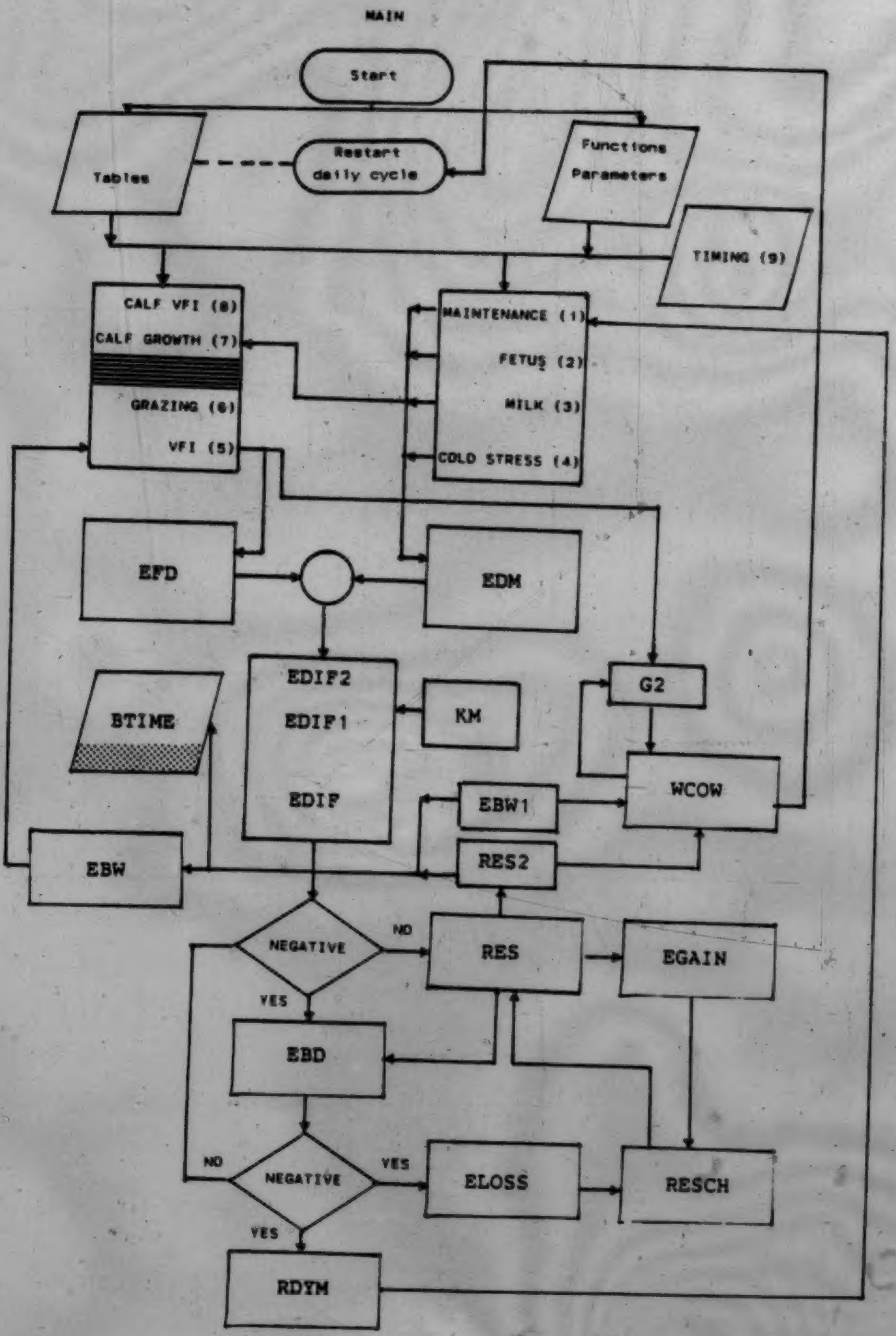
Connector



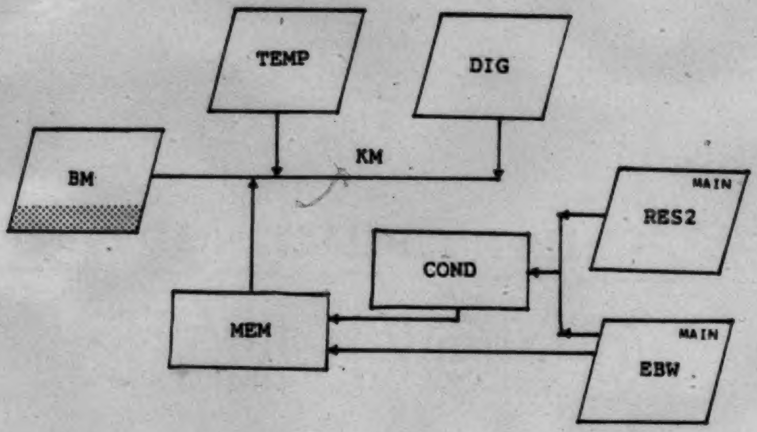
Decision



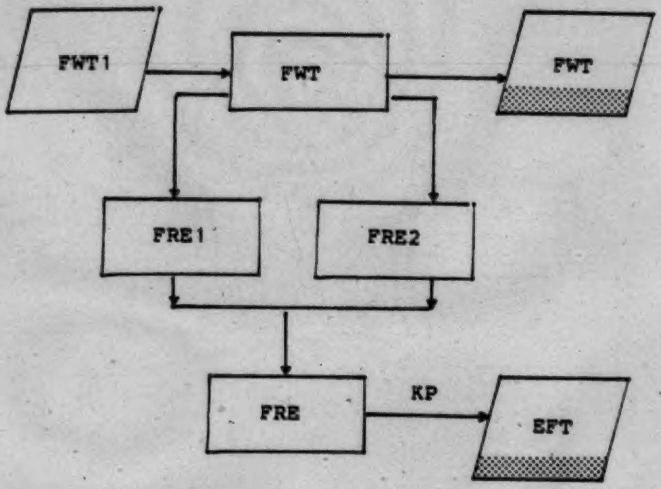
Start

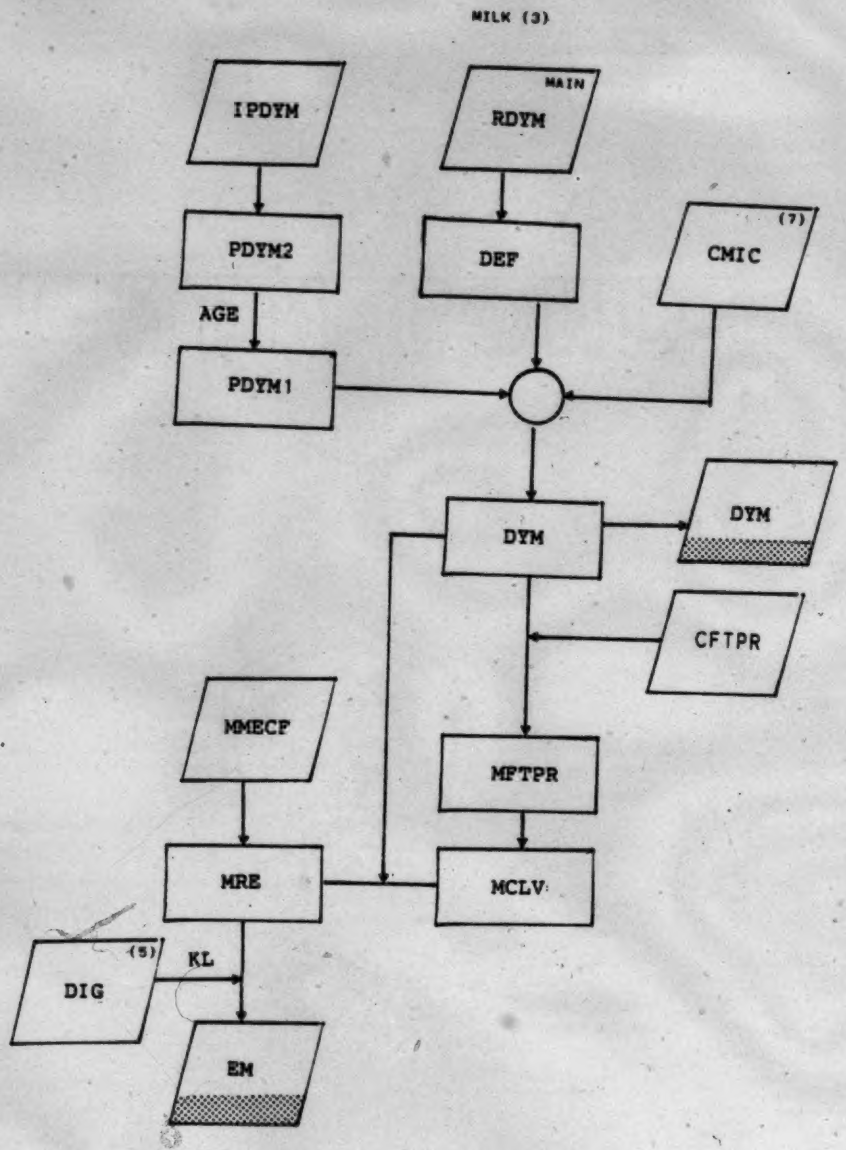

MAIN
Start
Tables
Restart daily cycle
Functions Parameters
TIMING (9)
CALF VFI (8)
CALF GROWTH (7)
GRAZING (6)
VFI (5)
MAINTENANCE (1)
FETUS (2)
MILK (3)
COLD STRESS (4)
EFD
EDM
EDIF2
EDIF1
EDIF
KM
G2
BTIME
WCOW
EBW1
RES2
EBW
NEGATIVE
NO
YES
RES
EGAIN
EBD
NO
NEGATIVE
YES
ELOSS
RESCH
YES
RDYM

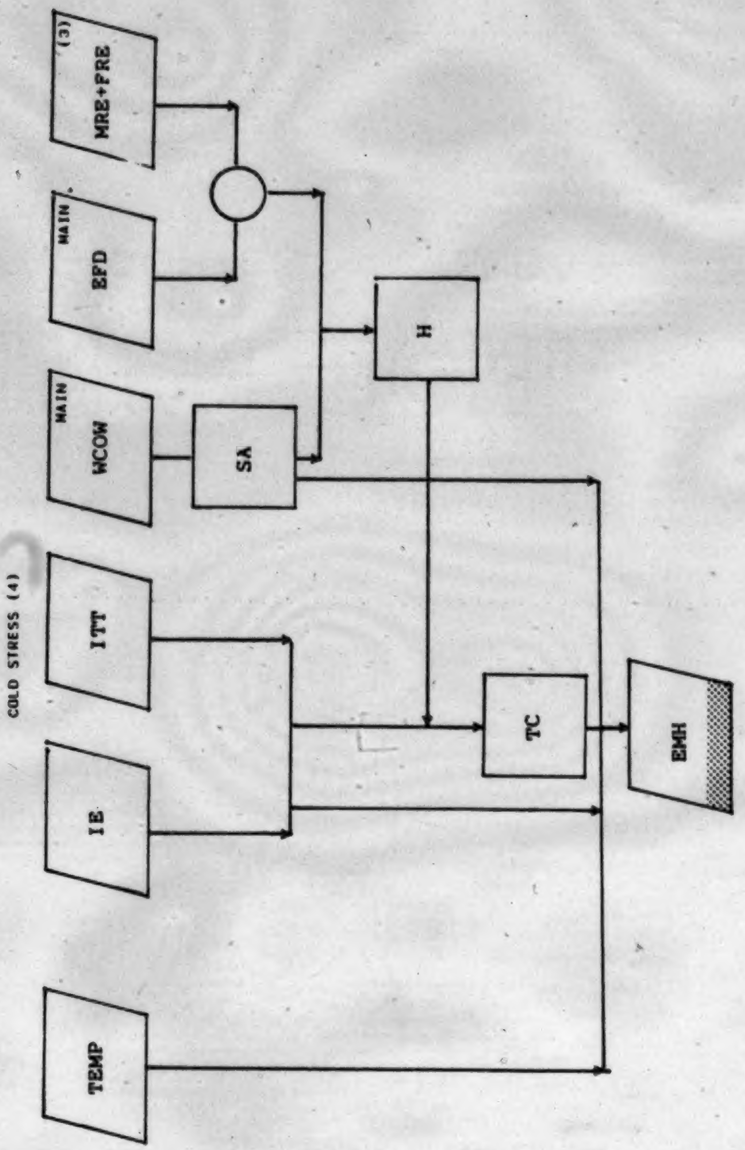
MAINTENANCE (1)

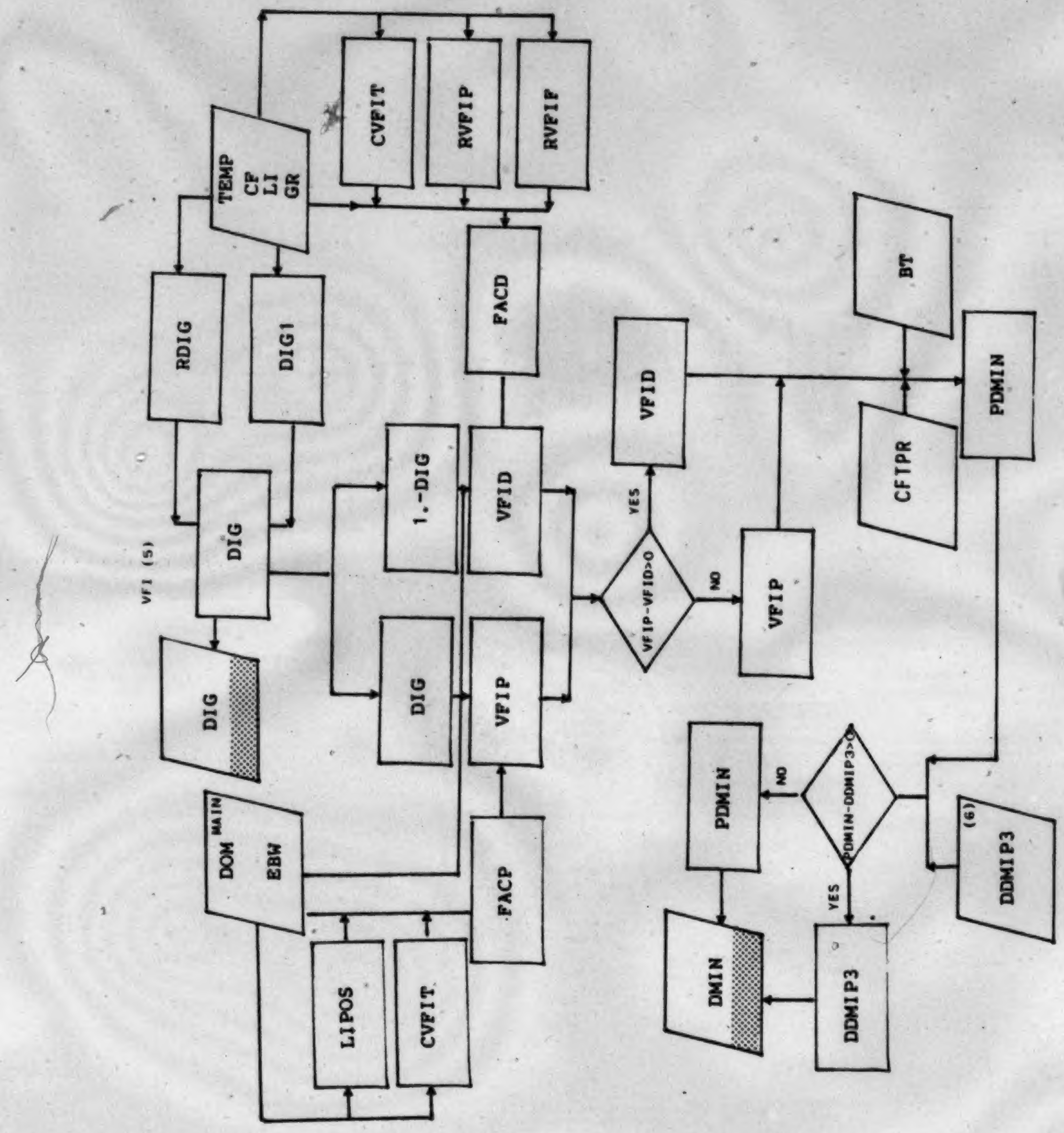

TEMP
DIG
BM
KM
MAIN
RES2
COND
MEM
MAIN
EBW

FETUS (2)

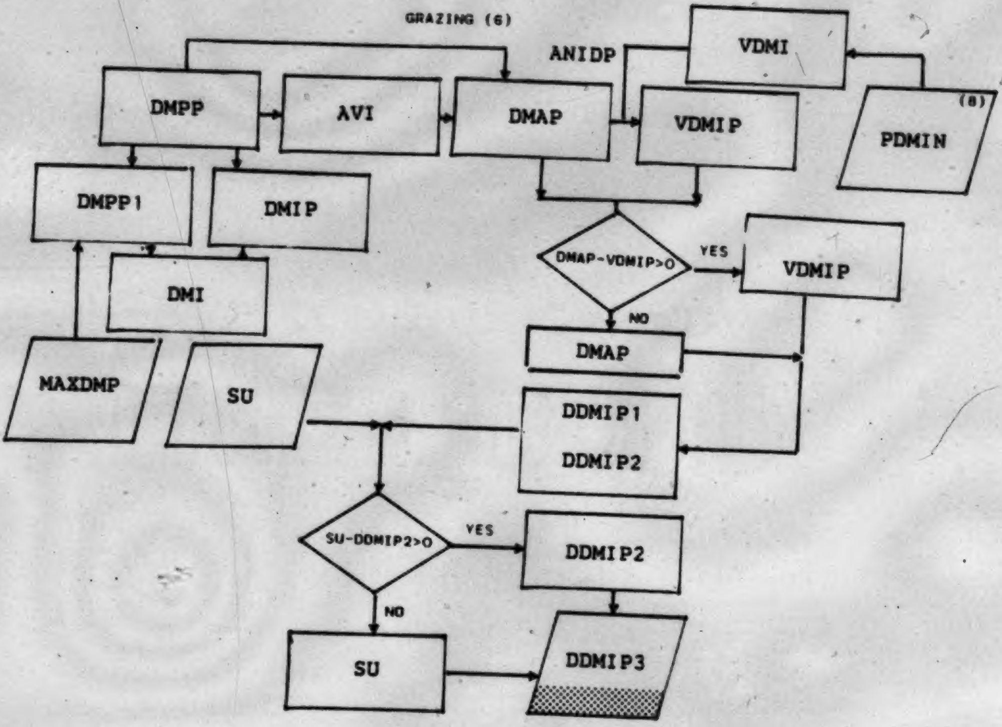

FWT1
FWT
FWT
FRE1
FRE2
FRE
KP
EFT


MILK (3)
IPDYM
RDYM
MAIN
PDYM2
DEF
CMIC
(7)
AGE
PDYM1
DYM
DYM
CFTPR
MMECF
MFTPR
MRE
MCLV
DIG
(5)
KL
EM

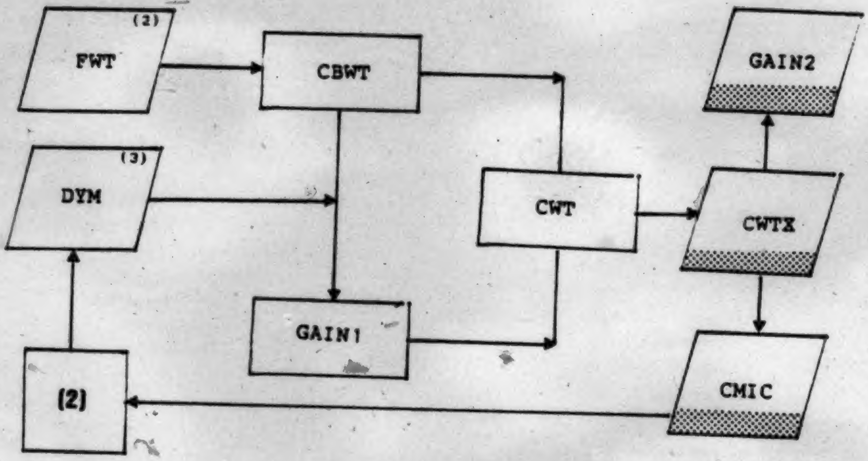

COLD STRESS (4)
MRE+FRE
(3)
EFD
MAIN
WCOW
MAIN
ITT
IE
TEMP
SA
H
TC
EMH

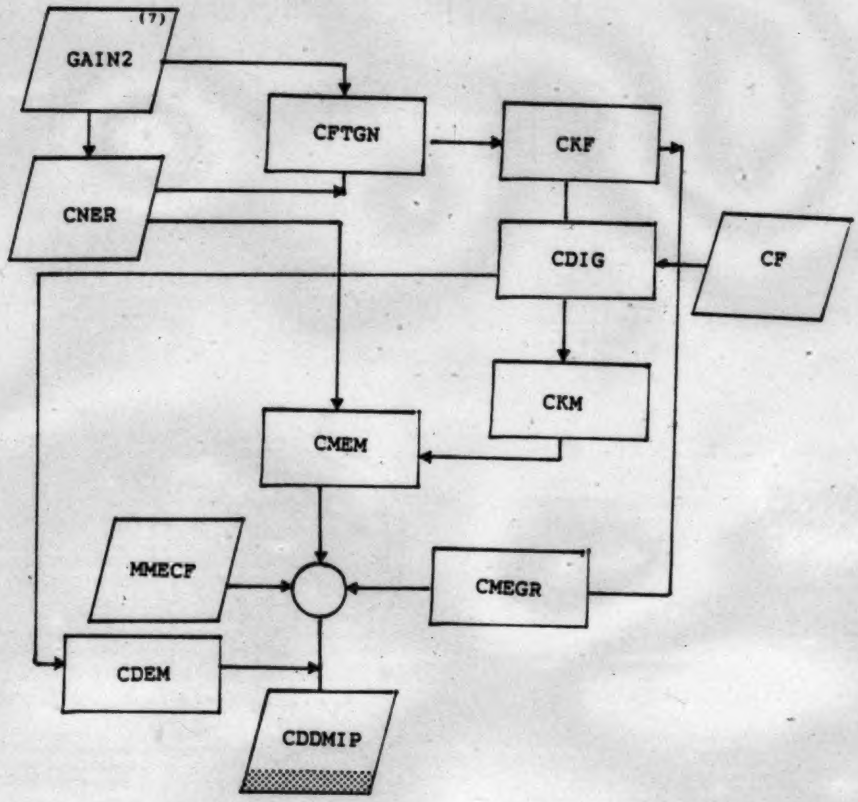

TEMP
CF
LI
GR
CVFIT
RVFIP
RVFIF
RDIG
DIG1
FACD
VFI (5)
DIG
1.-DIG
VFID
DIG
VFIP
VFIP-VFID>0
YES
NO
VFID
VFIP
BT
CFTPR
PDMIN
DOM MAIN
EBW
FACP
LIPOS
CVFIT
PDMIN-DDMIP3>0
NO
YES
PDMIN
(6)
DDMIP3
DMIN
DDMIP3

GRAZING (6)


ANIDP
VDMI
DMPP
AVI
DMAP
VDMIP
(8)
PDMIN
DMPP1
DMIP
DMI
DMAP-VDMIP>0
YES
VDMIP
NO
DMAP
MAXDMP
SU
DDMIP1
DDMIP2
SU-DDMIP2>0
YES
DDMIP2
NO
SU
DDMIP3

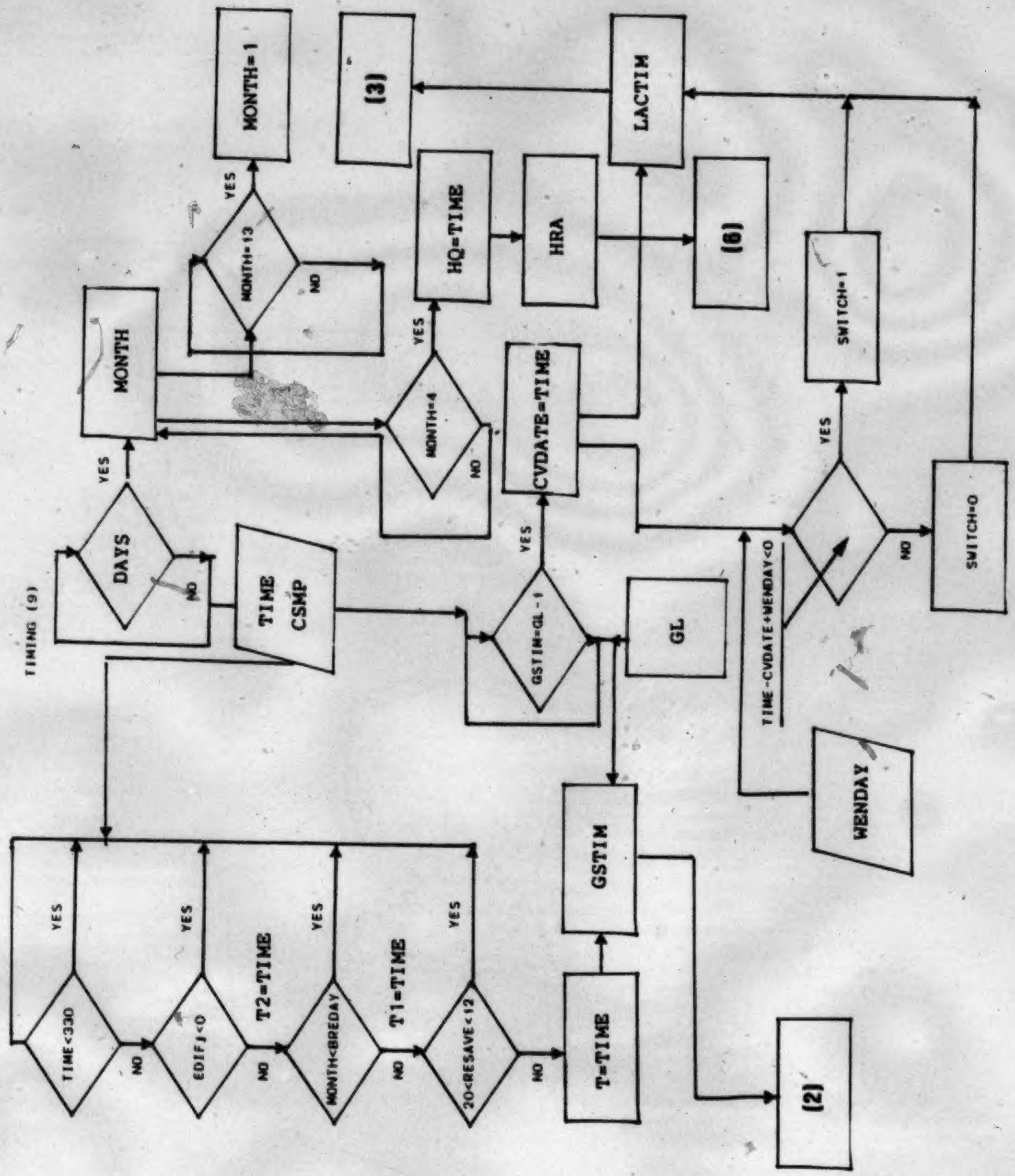
CALF GROWTH (7)

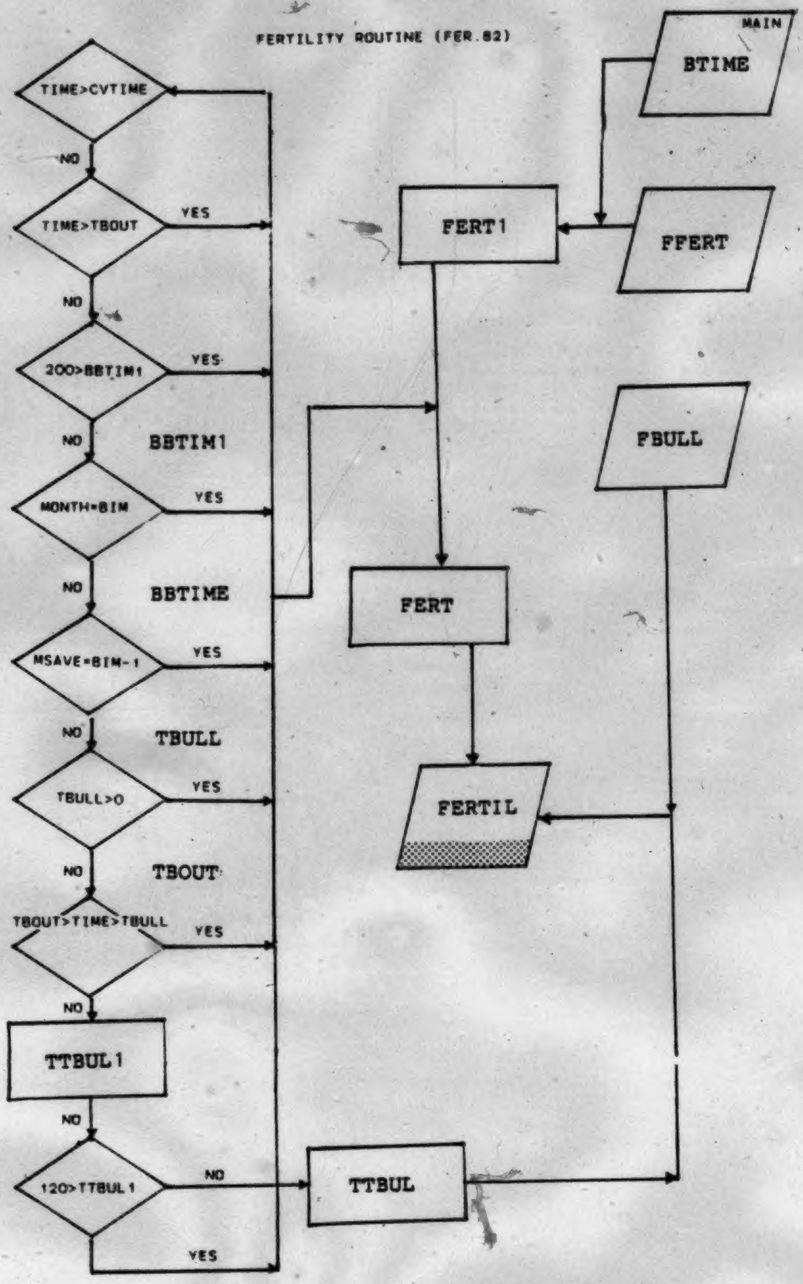

(2)
FWT
CBWT
GAIN2
(3)
DYM
CWT
CWTX
GAIN1
(2)
CMIC



CALF VFI (8)

(7)
GAIN2
CFTGN
CKF
CNER
CDIG
CF
CKM
CMEM
MMECF
CMEGR
CDEM
CDDMIP


TIMING (9)
DAYS
YES
NO
MONTH
MONTH=13
YES
NO
MONTH=1
MONTH=4
YES
NO
HQ=TIME
HRA
[6]
[3]
LACTIM
TIME
CSMP
GSTIM=GL-1
YES
CVDATE=TIME
GL
TIME-CVDATE+WENDAY<0
YES
NO
SWITCH=1
SWITCH=0
WENDAY
GSTIM
[2]
TIME<330
YES
NO
EDIFj<0
YES
NO
T2=TIME
MONTH<BREDAY
YES
NO
T1=TIME
20<RESAVE<12
YES
NO
T=TIME



FERTILITY ROUTINE (FER.82)

TIME>CVTIME
NO
TIME>TBOUT
YES
NO
200>BBTIM1
YES
NO
BBTIM1
MONTH=BIM
YES
NO
BBTIME
MSAVE=BIM-1
YES
NO
TBULL
TBULL>0
YES
NO
TBOUT
TBOUT>TIME>TBULL
YES
NO
TTBUL1
NO
120>TTBUL1
NO
YES
TTBUL
MAIN
BTIME
FERT1
FFERT
FBULL
FERT
FERTIL

```
$RUN *CSMPTRAN
TITLE MATURE COW PRODUCTIVITY MODEL -------(COW.82)
TITLE BREEDS ARE:1-HE, 2-SY 3-DY
*
*               1. INITIAL VALUES
*               ******************
*
*
NOSORT
**************************************************HE
       IPDYM=9.3
       Y=.1521
       GL=286.
       BWT=32.8
       CBWT=(BWT+.4)*1.035
       PIGN=.776
       R1=.0006391
       GRP1=6.4527E-5
       GRP2=1.8
       CFFTPR=1.3
       WCOWIN=475.
       DOMB=.068
       LIP=.8
***************************************************SY
       IF(BREED.EQ.1) GO TO 3
       IPDYM=10.2
       Y=.1203
```

```
      GL=283.
      BWT=34.6
      CBWT=(BWT+1.27)*1.035
      PIGN=.932
      R1=.0006970
      GRP1=4.746E-4
      GRP2=1.5
      CFFTPR=1.25
      WCOWIN=525.
      DOMB=.068
      LIP=.8
*****************************************************DY
      IF(BREED.EQ.2) GO TO 3
      IPDYM=10.5
      Y=.0938
      GL=282.
      BWT=38.2
      CBWT=(BWT+1.94)*1.035
      PIGN=1.011
      R1=.0007822
      GRP1=5.0E-4
      GRP2=1.5
      CFFTPR=1.26
      WCOWIN=520.
      DOMB=.074
      LIP=.3
    3 CONTINUE
```

```
SORT
**********
GROWTH,RESERVES,MILK,ENERGY***********************
          A=BWT/DOMB
          K=(PIGN/(A*.64))
          LWT=(A*(1.-EXP(-K*DDELAY)))
          WCOWI=WCOWIN-CBWT
          RESI=WCOWI*RESFC
          RES12=RESI/4.91
          RES2=RES12
          BWI=WCOWI-RES2
          AI=DEF1-(DEF2/DEF3)*DELT
          DDELAY=2000.
          CMIC=(CBWT**.5332)*.93
          DYM=CMIC
          PDYM=CMIC
          PDYM1=CMIC
          RES=RESI
          LI=1.3
          EDIF=0.0
          EDIF1=0.0
          FWT=0.0
          PDRU=RESI*RESUS
          EBD=PDRU
          G2=AMIN1(.97,(.87+(12.3-(1.38*CF))/LWT))
          EBW1=BWI*G2
          RESAVE=RES2/(EBW1+RES2)
          TEMP=2.9
DYNAMIC
**********
****PHYSIOLOGICAL AND MANAGERIAL PARAMETERS AND SWITCHES*
           SWITCH=INSW(TIME-(CVDATE+WENDAY),1.,0.0)
           SW1=INSW(TIME-(CVD+WENDAY-1.),1.,0.0)
           FUNCTP=INSW(TIME-275.,FNCTP1,FNCTP2)
           TEMP=AFGEN(FUNCTP,MONTH)
           LACTIM=((TIME-CVDATE)/30.)*SWITCH
           AGE=AINT(((DDELAY+TIME)/365.)+.5)
           LWT=A*(1.-EXP(-K*(TIME+DDELAY)))
           DOM=LWT/A
           G2=AMIN1(.97,(.87+(12.3-(1.38*CF))/LWT))
NOSORT
           EBW=EBW1+RES2
           IF(TIME.NE.CVDATE+1) GO TO 226
           DYM=CMIC
           DEFSW=DEF11
           TFCM1=TFCM2
      226  CONTINUE
*********DIGESTIBILITY***************************************


RDIG=((105.27+(-4.58+(-.052*GR))*LI)/100.)*(1.-F*(20.-TEMP))
        DIG1=(88.-1.047*CF)/100.
        DIG=AMAX1(.3,RDIG*DIG1)
********MILK REDUCTION**************************************
```

```
MFTPR=INSW(-DYM,(5.072-(.276*DYM))*CFFTPR*SWITCH,0.0)
      NERM=.3602*MFTPR**.5226
      EM1=AMAX1(0.0001,NERM*DYM)
      RDYM=LIMIT(.0,PDYM1,-EDIF/EM1)*SWITCH
*********DRY MATTER INTAKE************************************
      IVFILC=AFGEN(FVILC,LACTIM)
      RVFIP=(1.-FWT/400.)
      AFTPR=.0072*LWT
      RVFIF=1.-(AFTPR/40.)
      LIPOS=INSW(RESAVE-.25,LIPO,1.-(RES2/EBW)**.3)
      LIPO=INSW(RESAVE-.20,1.,1.-(RES2/EBW)**LIP)
      CVFIT=1.+.0033*(20.-TEMP)
      FACP=CVFIT*LIPOS
      FACD=CVFIT*RVFIP*RVFIF
      VFIP=(((.1145-.0717*DOM)/DIG)*EBW**.75)*FACP
      VFID=(((.044-.0167*DOM)/(1.-DIG))*EBW**.75)*FACD
      BT=((A/480.)**.75*(IPDYM/9.3))**.3
      PDMIN=AMIN1(VFIP,VFID)*IVFILC*1.2*BT
      DMIN=INSW(-TIME,AMIN1(DDMIP3,PDMIN),PDMIN)
********ENERGY FROM BODY RESERVES*****************************
          BD=AMIN1(PDRU,RES/DELT)
          EBD=INSW(-EDIF1,0.0,BD)
SORT
*
********MILK POTENTIAL & PRODUCTION*************************
*
```

```
        LACTID=INSW(TIME-CVDATE,0.0,TIME-CVDATE)
        PDYM2=IPDYM*EXP(-Y*LACTIM)*(AGE*E1-E2*AGE**2+E3)
        PDYM1=AMAX1(0.,PDYM2-DEF)*SWITCH
DEF22=((INTGRL(DEF0,(AMAX1(DEF,RDYM)-DEF)/DELT-AI*DEF)))
     DEF11=DEF22-DEFSW
     DEF=DEF11*SW1
NOSORT
        DYM=AMAX1(0.0,AMIN1(CMIC,(PDYM1-RDYM)))

MFTPR=INSW(-DYM,(5.072-(.276*DYM))*CFFTPR*SWITCH,0.0)
SORT

********ENERGY IN THE MILK*********************************
*
*
        MCLV=MFTPR*D1+D2
        MRE=DYM*NERM
        KL=.81-(.1/DIG)
        EM=MRE/KL

*******FETAL GROWTH*****************************************
*
*********************************************CONCEPTION TIME
      GSTIM1=INSW((TIME-T),0.0,TIME-T)
      GSTIM=INSW(GSTIM1-GL,GSTIM1,0.0)
************************************************FETAL WEIGHT
      FWT1=R1*EXP(R2*GSTIM-R3*GSTIM**2)
```

```
       FWT=INSW(-GSTIM,FWT1,0.0)
***********************************RETENTION ENERGY IN FETUS


FRE1=F1*(F2-2.*F3*GSTIM)*EXP(F2*GSTIM-F3*GSTIM**2)*.0094

FRE2=P1*(P2-2.*P3*GSTIM)*EXP(P2*GSTIM-P3*GSTIM**2)*5.6
       FRE=INSW(-GSTIM,(FRE1+FRE2),0.0)
       KP=.375*DIG-.05
       EFT=FRE/KP
**************************************TECHNICAL ADJUSTMENTS

NOSORT
       IF(GSTIM.EQ.GL-1) CBWT=FWT
       IF(TIME.NE.CVDATE+1) GO TO 555
       CWT1=CAWT1
   555 CONTINUE
SORT
FCM=DYM*.4+DYM*MFTPR*.15

***********CALF PRODUCTION**********************************
***********************CALF MILK CAPACITY (LIQUID & ENERGY)
CMIC=INSW(-LACTIM,CMIC1,(CBWT**.5332)*.93)
CMIC1=AMIN1((CWT**.5332)*.93,((CWT**.67272)*.3678)/(MCLV*.9))

*****************MILK'S METABOLIZABLE ENERGY VALUE  FOR CALF
         MMECF=DYM*.9*MCLV
```

```
**********CALF GROWTH
          GAIN1=AMAX1(0.0,(MMECF*.179)-(.00033*(CWTX**1.5)))
NOSORT
          IF(CWTX.GT.CWT) GO TO 964
          IF(GAIN1.GT.GNSAV1) LACTIN=LACTID
          GRP0=(1.-(GRP1*LACTIN**GRP2))
   964    CONTINUE
SORT
***************************************************CALF WEIGHT
          CAWT1=(INTGRL(0.0,GAIN1))
          CAWT=CAWT1-CWT1
          CWT=(CBWT+CAWT)*SWITCH
CWTX=INSW(LACTID-150.,CWTX1,CWTX2+GNSAV2)*SWITCH
CWTX3=INSW(LACTID-70.,CWT,(GRP0+(GRP1*LACTID**GRP2))*CWT)
CWTX1=INSW(GNSAV1-GAIN1,CWTX3,(GRP0+(GRP1*LACTID**GRP2))*CWT)

GAIN2=FCNSW(GAIN1-GNSAV1,CWTX-CWTX2,GNSAV2,GAIN1)
******************************************************CALF VFI

NOSORT
          IF(LACTID.EQ.1) CWTX=CWT
          GNSAV1=GAIN1
          GNSAV2=GAIN2
          CWTX2=CWTX
          IF(GAIN2.EQ.0) GO TO 176
          CNER=(.05437*GAIN2+.00824*(GAIN2**2))*CWTX**.75
          CFTGN=(((CNER/GAIN2)-1.23)/8.6)/.35
          CFFGN=1.-CFTGN
          CDIG=DIG1*(1.-F*(20.-TEMP))
          CKM=.54+.24*CDIG
          CKF=(.660*CDIG-.07)*CFFGN+(.333*CDIG+.148)*CFTGN
          CMEM=((.077*CWTX**.75)*(1.+.008*(20-TEMP)))/CKM
          CMEGR=CNER/CKF
          CDEM=CDIG*4.112-.115
          CDDMIP=(AMAX1(0.0,(CMEGR+CMEM-MMECF)/CDEM))*SW1
  176     CONTINUE
SORT
*
*
*
*********ENERGY BALANCE IN COW ******************************
*
*
         EDIF2=(EFD-EDM)
         EDIF1=INSW(EDIF2,EDIF2*.70,EDIF2*KF)
         EDIF=EDIF1+EBD
************************************ENERGY DEMAND MCAL/DAY ME
         EDM=INSW(-TIME,BM+EM+EFT+EMH,EFD)
*******ENERGY FOR MAINTENANCE  AND UTILIZATION EFFICIENCIES
         BM=(MEM*(1.+0.008*(20-TEMP)))/KM
         KF=INSW(-LACTIM,.62,.03+.662*DIG)
         COND=1.-(RES2/EBW)
         MEM1=(.077*EBW**.75)*COND
         MEM=INSW(-LACTID,MEM1*1.007,MEM1)
```

```
          KM=0.54+0.24*DIG
*          FCM=DYM*0.4+DYM*MFTPR*0.15
*          TEDM=INTGRL(20.,EDM)
****ENERGY CONCENTRATION IN THF FEED AND MAINTENANCE LEVEL
          DME=DIG*4.112-.115
          EFD=DME*DMIN
          LI=EFD/BM
NOSORT
          CVGN=4.91
          IF(EDIF1.GT.0.AND.RESAVE.LT..20.AND.LACTIM.GT.0)
CVGN=3.50
SORT
*
***********BODY WEIGHT****************************************
*
           FW=INSW(-TIME,0.0,CBWT)
************************************COW LIVE WEIGHT AND GAIN

           WCOW=(EBW1/G2)+RES2+FWT+FW
**************RESERVE DEPOT WEIGHT & GAIN AND EMPTY BODY
GAIN
           RES22=(RES-RSAVE)/CVGN
           RES2=INTGRL(RES12,RES22)
*
*
*
***********BODY RESERVE BALANCE*****************************
```

```
*
*
*
          RES1=INTGRL(0.0,RESCH)
          RES=RESI+RES1
          PDRU=RES*RESUS
          RESCH=INSW(EDIF1,ELOSS,EGAIN)
          ELOSS=LIMIT(-PDRU,0.,ELOSS1)
          ELOSS1=INSW(RES+ELOSS2,0.0,ELOSS2)
          ELOSS2=(EDIF1)
          EGAIN=INSW(EDIF1,.0,EDIF1)
*
******TIMING*********************************************
NOSORT
       IF(TIME-T.LT.330.OR.EDIF1.LT.0.0) GO TO 19
       T2=TIME
       IF(MONTH.LT.BREDAY) GO TO 19
       T1=TIME
       IF(RESAVE.LT..12.OR.RESAVE.GT.20) GO TO 19
       T=TIME
    19 RESAVE=RES2/EBW
       RSAVE=RES
       IF(GSTIM.EQ.(GL-1)) CVDATE=TIME
       IF(TIME.EQ.CVDATE+1) CVD=TIME
       DAYS=AFGEN(FDAYS,MONTH)
       MONT=MONTH
       MONTH=INSW(TIMM-DAYS,MONT,MONT+1.)
       IF(MONTH.EQ.13) MONTH=1.
       IF(TIMM.EQ.DAYS) TIMM=0.
       TIMM=TIMM+1.
       IF(MONTH.NE.4) GO TO 1
       IF(TIMM.LT.2) HQ=TIME
     1 CONTINUE
SORT
*
*
*********GRAZING**********************************
*********VOLUNTARY DRY MATTER INTAKE OF COW(KG/DAY)
VDMI=PDMIN
************************************DAYS OF GRAZING
HRA=TIME-HQ
*************************PASTURE PRODUCTION (KG/HA)
DMPP1=INSW(HRA-200.,(MAXDMP*(1.-EXP(-.0121*HRA))),2000.)
****************DAILY PASTURE PRODUCTION (KG/HA/DAY)
DDMP=DER4(0.0,DMPP1)
*********************NET PASTURE LEFT AFTER GRAZING
DMPP=AMAX1(0.0,DMPP1-DMIP)
*************CRUDE FIBER IN PASTURE & DIGESTIBILITY
CFP=AFGEN(FCFP,MONTH)
******************PASTURE AVAILABILITY  (KG/HA/DAY)
AVI=AMIN1(1.,.0007*DMPP)
DMAP=DMPP*AVI
*ANIDP=AFGEN(FANIDP,MONTH)
VDMIP=VDMI*ANIDP
```

```
DDMIP1=AMIN1(DMAP,VDMIP)
*******************ACTUAL PASTURE DRY MATTER INTAKE
****************************************(KG/HA/DAY)
DDMIP=INSW(HRA-DELAY1,0.0,DDMIP1)
************************************(KG/ANIMAL/DAY)
DDMIP2=DDMIP/ANIDP
NOSORT
      IF(HRA.EQ.1.AND.TIME.GT.11) DMI=DMIP1
SORT
DDM=INSW(M1-8.,DDMIP+CDDMIP*ANIDP,0.0)
DMIP1=INTGRL(0.0,(DDM))
DMIP=DMIP1-DMI
NOSORT
*
*******SUPPLEMENTATION*****************************
*
      IF(MONTH.GT.4) M1=MONTH-4.
      IF(MONTH.LE.4) M1=MONTH+8.
      SU=6.5
      IF(MONTH.EQ.4.AND.TIMM.GT.10) SU=DDMIP2
      IF(MONTH.EQ.4.AND.TIMM.LE.10) SU=PDMIN
      DDMIP3=INSW(M1-8.,DDMIP2,SU)
      CF=INSW(M1-8.,CFP,30.)
      GR=INSW(M1-8.,0.0,.07)
      IF(MONTH.NE.4.OR.TIMM.GT.10) GO TO 137
      CF=30.
      GR=0.0
```

```
   137 CONTINUE
 SORT
 *
 *
 ***********CRITICAL ENVIRONMENT****************************
 *
 ***************************************CRITICAL TEMPERATURE
           TC=(39.+(0.36*IE)-H*(IE+ITT))
           SA=0.09*WCOW**.67
           Z1=INSW(TEMP-TC,1.,0.)
 **************ADDITIONAL ENERGY FOR BODY TEMP. MAINTENANCE
           EMH=Z1*SA*(TC-TEMP)*(ITT+IE)
           H1=(EFD-(MRE+FRE))
           H=H1/SA
 ****************************INSULATION AND CLIMATIC FACTORS
           ITT=AFGEN(FNCIT,LWT)
           IE=AFGEN(FNCIE,WSPD)
           WSPD=1.1
 *************************EXPERIMENTAL VALUES FOR VALIDATION
NOSORT
       WCOWX=INSW(TIME-551.,AFGEN(FHEWTX,TIME),WCOW)
       IF(BREED.EQ.1) GO TO 188
       WCOWX=INSW(TIME-551.,AFGEN(FSYWTX,TIME),WCOW)
       IF(BREED.EQ.2) GO TO 188
       WCOWX=INSW(TIME-551.,AFGEN(FDYWTX,TIME),WCOW)
   188 CONTINUE
SORT
```

```
*****VALUES OF PARAMETERS AND EXTERNAL TABULAR FUNCTIONS***
*
*
PARAM RESFC=0.196,RESUS=0.05,DEF0=0.,...
DEF1=0.1,DEF2=0.04,DEF3=20.,F=.0011,...
T=75.0,CVDATE=0.0,DDMIP3=10.,CF=30.,...
WENDAY=180.,ANIDP=.8,MONTH=4.,DELAY=0.0,BREDAY=6.,BREED=2.,...

D1=0.1122,D2=.299,G1=.90,KF=.620,...
R2=0.0738,R3=0.0001249,E1=0.1277,...
E2=0.0082,E3=0.4864,MP=0.,FWT=0.,GAIN1=0.,...
F1=.0007696,F2=.0885,F3=.0001282,P1=.000586,P2=.0589,P3=.00009334

PARAM MAXDMP=2300.,...
DMIP=0.,TIMM=0.,GR=0.,DMPP1=0.
FUNCTION
FDAYS=(1.,31),(2.,28.),(3.,31),(4.,30.),(5.,31.),...
(6.,30.),(7.,31.),(8.,31.),(9.,30.),(10.,31.),(11.,30.),(12.,31)

FUNCTION
FVILC=(0.,1.),(2.,1.2),(3.,1.32),(4.,1.33),(5.,1.34),...
(6.,1.33),(7.,1.24),(8.,1.22),(9.,1.20),(10.,1.14)
FUNCTION FNCTP1=(1.,-12.4),(2.,-8.1),(3.,-5.6),...
(4.,7.7),(5.,12.7),(6.,15.7),(7.,20.1),(8.,20.4),...
(9.,17.1),(10.,6.3),(11.,-2.8),(12.,-10.0)
FUNCTION FNCTP2=(1.,-19.8),(2.,-3.4),(3.,-3.2),(4.,8.4),...
(5.,11.6),(6.,15.2),(7.,15.6),(8.,13.1),(9.,9.5),...
```

```
(10.,5.1),(11.,-6.8),(12.,-18.6)
FUNCTION FNCIT=(40.,3.0),(100.,6.0),(300.,8.0),(600.,10.0)
FUNCTION FNCIE=(1.0,17.),(10.,6.0)
FUNCTION
FCFP=(1.,40.),(3.,40.),(4.,20.),(8.,25.),(9.,40.),...
(10.,40.),(12.,40.)
FUNCTION FHEWTX=(0.,475.),(28.,422.),(80.,463.),...
(153.,518.),(185.,517.),(284.,494.),(360.,493.),(392.,418.),...

(481.,485.),(515.,546.),(550.,517.),(760.,717.)
FUNCTION FSYWTX=(0.,525.),(28.,461.),(80.,508.),...
(153.,571.),(185.,565.),(284.,549.),(360.,540.),(392.,486.),...

(481.,543.),(515.,581.),(550.,545.),(760.,545.)
FUNCTION FDYWTX=(0.,520.),(28.,454.),(80.,500.),...
(153.,571.),(185.,542.),(284.,518.),(360.,537.),(392.,470.),...

(481.,544.),(515.,580.),(550.,530.),(760.,530.)
*FUNCTION
FANIDP=(1.,1.0),(3.,1.0),(4.,.8),(5.,.8),(6.,0.8),...
*(8.,0.8),(9.,.8),(11.,.8),(12.,1.0)
METHOD RECT
PRINT
WCOW,WCOWX,EBW,LWT,DIG,DMIN,PDMIN,CDDMIP,FWT,CWTX,EFD,...
EDM,FCM,DYM,RDYM,DEF,MFTPR,RES2,RESAVE,TIME,T,T1,T2,CVDATE,...

EDIF1,EDIF,PDRU,EMH,H1,BM,LI,TEMP,TC,MONTH,CWT,...
```

```
GAIN1,GAIN2,DMI,DMPP
TIMER FINTIM=760.,DELT=1.0,PRDEL=20.
END
STOP
ENDJOB
$RUN *FORTG SCARDS=-CSMP#7
$RUN *CSMPEXEC+-LOAD#+SIMOUT.O+*CSMPLIB  15=-PLINFO 6=-8
```

```
RUN *CSMPTRAN
TITLE FERTILITY MODEL    ---------(FER.82)
******************************
*
/       DIMENSION X(7),Y(7)
/       DATA X/0.,1100.,1450.,1800.,2150.,2500.,2850./
/       DATA Y/88.,60.,50.,55.,62.,80.,43./
FIXED J
FUNCTION
FFERT=(0.,0.),(40.,.20),(50.,.45),(60.,.61),(70.,.79),...
                   (80.,.88),(90.,.92),(200.,.95)
FUNCTION
FBULL=(0.,0.),(5.,.05),(15.,.20),(25.,.50),(35.,.80),...
                   (45.,.90),(55.,.95),(65.,1.),(285.,1.)
FUNCTION
FDAYS=(1.,31),(2.,28.),(3.,31),(4.,30.),(5.,31.),...
(6.,30.),(7.,31.),(8.,31.),(9.,30.),(10.,31.),(11.,30.),(12.,31)

PARAM
BIM=6.,BID=1.,BOD=90.,TIMM=0.,MONTH=4.,TBULL=0.,CVTIME=380.
J=1
DYNAMIC
********
NOSORT
       DAYS=AFGEN(FDAYS,MONTH)
       MONT=MONTH
       MONTH=INSW(TIMM-DAYS,MONT,MONT+1.)
```

```
      IF(MONTH.EQ.13) MONTH=1.
      IF(TIMM.EQ.DAYS) TIMM=0.
      TIMM=TIMM+1.
      IF(TIME.NE.X(J)) GO TO 1
      CVTIME=X(J)
      BTIME=Y(J)
      J=J+1.
      FERT1=.8/(AFGEN(FFERT,BTIME))
    1 CONTINUE
      IF(TIME.EQ.0) GO TO 10
      BBTIM1=TIME-CVTIME
      IF(TIME.GE.CVTIME) GO TO 8
      BBTIM1=0.
 8    CONTINUE
      IF(TIME.GE.TBOUT) BBTIME=0
      BBTIME=INSW(200.-BBTIM1,0.,BBTIM1)
      FERT=AMIN1(.95,((AFGEN(FFERT,BBTIME))*FERT1))
      IF(MONTH.EQ.BIM.AND.MSAVE.EQ.BIM-1) TBULL=TIME+BID
      MSAVE=MONTH
      IF(TBULL.GT.0) TBOUT=TBULL+BOD
      TTBUL1=TIME-TBULL
      IF(TIME.GE.TBULL.AND.TIME.LE.TBOUT) GO TO 9
      TTBUL1=0.
 9    CONTINUE
      TTBULL=INSW(120.-TTBUL1,0.,TTBUL1)
      BULL=(AFGEN(FBULL,TTBULL))
 10   CONTINUE
```

```
SORT

FERTIL=FERT*BULL

NOSORT

SORT

TERMINAL

********

TIMER FINTIM=150.,DELT=1.,PRDEL=10.

PRINT FERTIL,FERT1,FERT,BULL,TBOUT,TTBULL,BBTIME,MONTH

METHOD RECT

END

STOP

ENDJOB

$RUN *FORTG SCARDS=-CSMP#7

$RUN *CSMPEXEC+-LOAD#+*CSMPLIB  15=-PLINFO 6=-7
```

SUMMARY IN HEBREW

ניתוח מערכות בקר לבשר במדינת אלברטה (קנדה)

סיכום כללי

מודל סימולציה דטרמניסטי העוסק במערכות משולבות של בקר לבשר, פותח ותוכנת בשפת המחשב CSMP /360, וכן הורץ במטרה לחקור את השפעת הגורמים הסביבתיים של מרכז אלברטה על הפוריות והיעילות היצרנית של שלושה גיזעי בקר לבשר תחת משטר רעיה. הגזעים שנחקרו היו הרפורד (HE), בקר לבשר סינטטי (SY), ובקר לבשר-חלב סינטטי (DY). על פי המודל שיעור הגדילה, תפוקת החלב ורמת הפוריות הנם פונקציה של התורשה, תנאי הגוף ורמת ההזנה. רמת הצריכה קשורה בנעכלות המספוא ונאכלותו, והנאכלות מחושבת כפונקציה של גודל הגוף, הדרישות התזונתיות וזמינות המיספוא ונעכלותו.

המטרה הראשונית בפיתוח המודל, היתה בתאור מדויק ככל האפשר של תהליכים ביולוגים. אם תהליכים שכאלה ויחסי גומלין שבין תהליכים יתוארו במדויק במונחים כמותיים יהיה זה אפשרי לחזות את רמת היצור של הפרה באמצעות הסימולציה. מודל הסימולציה שעמד במרכזה של עבודה זו (פרק 3), הורכב ממערך של יחסי גומלין בין הפוטנציאל התורשתי כפי שנילמד במחקרים קודמים, וההשפעה הסביבתית כפי שנילמדה באמצעות איסוף נתונים בשטח. המודל המוצע מסוגל לחזות שינויי משקל יומיים ותקופתיים, תנובת חלב, גדילת עובר, תפוקת ולדות, רמת נאכלות ונעכלות, יעילות ניצול אנרגיה, תחלופת רקמות איחסון ופעילות רעיה. כמו כן המודל בנוי לחשב רמת פוריות, תמותת ולדות ועקת קור. נתוני מידע עבור המודל כוללים את הרקע התורשתי של הפרה, הערך התזונתי של מזונות אפשריים ותנאי האקלים. המודל נימצא מתאים ומדויק בכל שלושת הגזעים בחיזוי גדילה, אכילה ומספר תכונות של גדילת ולדות וגמילה.

ההבדלים שבין הגזעים עבור השנים 1976-77 תוארו גם הם באמצעות הסימולציה.

מאחר וכך, המודל שפותח שימש בחקר השפעתם של שינויים ברמת היצור. במחקר ראשון שבו נעשה שימוש במודל ככלי לניסוי (פרק 4), נחקרה השפעת השיפור בהזנת החורף, השפעת הטמפרטורה והשפעת ההזנה השנתית על רמת יצור הפרה. נימצא כי הריכוז האנרגטי של המנה הוא המרכיב החשוב ביותר בתקופה הראשונית מיד לאחר ההמלטה. השפעתו על משקל הגוף היא בעיקר באמצעות הגידול במשקל גוף ריק (ללא תכן מעי). תכולת התאית במנה היא המרכיב החשוב ביותר בתקופת התעצות צמחי המרעה בסוף תקופת הרעיה והשפעתה על משקל הגוף היא באמצעות הגידול בנפח תכן המעי. משקל העובר נימצא כאחד הגורמים המשמעותיים ביותר בשלב האחרון של ההריון, והשפעתו על משקל הגוף היא באמצעות הגידול במשקל הרחם.

במחקר שני שבו נעשה שימוש במודל ככלי לניסוי (פרק 5), נחקרה השפעת החריפה בתנאי חורף קשה על יצור הפרה בכל שלושת הגזעים. נימצא כי השפעת החורף הקשה באלברטה על משקל הפרה הוא זמני בלבד, כך שהשתקמות הפרה חוזתה ע"י המודל כאפשרית מיד בתחילת תקופת הרעיה המלווה את תקופת החורף הקשה. ההשפעה על הפוריות הוערכה ע"י המודל כמשמעותית יותר מזו שעל תכונות הגמילה.

במחקר שלישי שבו נעשה שימוש במודל ככלי לניסוי (פרק 6), נחקרה השפעת השימוש בגזעי בקר לחלב בתהליך הטיפוח של גזעי בקר לבשר. ששה טיפולים המשלבים רמות שונות של שני המרכיבים המכתיבים רמת יצור תנובה הושוו עם טיפול ביקורת שאופיין ע"י רמת התנובה של גזע ה (DY) כפי שנימדד ברמת יצור החווה. השפעתה של רמת התנובה ההתחלתית על תנובת החלב האמיתית ורמת היצור נימצאה כמועדפת על פני השפעתו של מקדם אחידות התחלובה (Persistency). הגדלת תנובת חלב תחילתית גרמה לעליה במשקל גמילה ולהפחתת מרווח המלטה, בעוד שהגדלת מקדם האחידות גרמה לעליה הן במשקל הגמילה והן במרווח ההמלטה.